BIOLOGICAL AND ECOLOGICAL STUDIES OF TWO SPOTTED SPIDER MITE (*TETRANYCHUS URTICAE* KOCH) AND ITS CONTROL ON HOPS IN TASMANIA

by

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graduated 1991

Submitted in fulfilment of the requirements for the degree of
Master of Agricultural Science

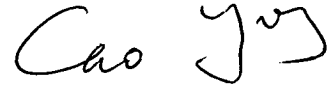
University of Tasmania
Australia
November 1989

TO

EVERY MEMBER IN MY FAMILY

DECLARATION

This thesis contains no material which has been used for the award of any other degree or diploma in any university. To the best of my knowledge and belief, it contains no material previously published or written by any other person, except where due reference has been made in the text of the thesis.



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ABSTRACT

This study was initiated in March 1987 and completed in March 1989. Aspects of the general biology and ecology of Two Spotted Spider Mite (TSSM), *Tetranychus urticae* Koch, and its natural enemies in hop fields were investigated in the years 1987-88 and 1988-89. The investigation found that TSSM overwinters in hollow cavities of hop twigs in the litter around hop rootstocks. In late August to early September TSSM becomes active to lay eggs and progressively colonizes hop on the lower surface of hop leaves. The teneral female mites of new generations were found to move upward with elongation of hop vines.The distribution patterns of the mites on hops vary with time and mite stage. In early or mid-March, mites move downward along hop vines to seek overwintering refuges.

The native predatory mite, *Amblyseius longispinosus* (Evans), was found to overwinter in the litter around the hop base. While the imported predatory mite, *Phytoseiulus persimilis* Athias-Henriot, cannot survive the Tasmanian winter.

The effects of TSSM feeding on hop production and the control of TSSM on hops by various means were studied in the two consecutive seasons. If unchecked, the mite can cause as much as 30% loss in cone production. The loss is mainly due to the reduction in numbers of cones hop plants produce under high mite feeding pressure. Damage was most often associated with large numbers of immature TSSM. However, mite populations can be effectively suppressed by either multiple application of Summer-oil/ Lime-sulphur, or the release of predacious mite *P. persimilis* at appropriate time.

A tolerance to mite feeding by hop plants was demonstrated. If insufficient numbers of cones are formed due to mite infestation, hop plants

will produce larger cones to achieve maximum production.

Two cultural activities can be effectively included into a TSSM control programme. Ploughing hop fields in late August - early September, after overwintering adults have moved onto notably thistles, can retard the build up of TSSM populations. Furthermore frequent use of overhead sprinkler irrigation of hop fields can result in suppression of TSSM populations.

Several simple ways of assessing TSSM densities on hops were assessed in 1987-88 and were employed throughout this study. A 'modified counting method' was developed for estimating mite densities using a mite-brushing machine. Adult female mite densities were estimated in hop fields by the naked eye and these counts related to total numbers of all mite stages.

In the phenology of the hop plant economic damage by mites was caused through infestation during the flowering phase and not by infestation of the earlier vegetation growth phase. Trial results indicated that application of Summer-oil during the post-vegetation phase could provide a potential alternative to conventional miticides.

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ACKNOWLEDGEMENTS

I wish to thank my supervisor, Dr. John L. Madden, Reader in Entomology at the Department of Agricultural Science for his continual help and encouragement throughout this study and for his constructive criticism in interpreting this work and in writing this thesis.

I am grateful to Mr. Tom Frankcomb for his generous offer to set up experimental plots in his commercial hop fields and his kind assistance in the conducting of this study.

I express my thanks to Hopunion Australia Inc. for the financial contribution and the access to the laser printer. Mr. John Ross, the managing director, is specially thanked for his helpful advice and continual assistance.

I am indebted to the University of Tasmania for the award of Postgraduate Research Scholarship and financial support to this project.

I am also grateful to Mr. Bill Peterson, Mr. D. Bradford and Mrs. Sally Jones, at the Department of Agricultural Science for their assistance in conducting this research.

Thanks are also due to Mrs. Margaret Williams, Entomologist at Department of Agriculture, New Town, Tasmania for her thoughtful advice and generous allowance for me to borrow a mite-brushing machine. Mr. Ken Davey and Mr. John Davey are thanked for their assistance when field investigations were conducted on their property.

I wish also to express my thanks to Mr. Xu-dong Wu and Mr. Zhong-jian Xu, Ph.D. students at the University of Tasmania, for their friendly encouragement and help in many ways while they were studying at the University of Tasmania.

I would like to express my gratitude to Mr. Alban Johnson and Mrs. Luci Johnson for their brotherly care and generous help while I am in

Tasmania.

I want to thank all those who helped me in various ways either directly or indirectly.

Finally, I am deeply indebted to every member of my family in China, particularly, my mother and my brother who would be most pleased to see the work is completed.

CHAPTER ONE

GENERAL INTRODUCTION

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1.1. HOPS

The hop plant, *Humulus lupulus* L., is used worldwide in brewing, as it has preservative power and provides special qualities such as aroma and bitterness to beers. The following paragraphs are mainly drawn and combined from Burgess (1964), Anon. (1975) and Anon. (1987).

The hop is a native wild plant of Europe and Western Asia. The first use of it, as mentioned by Pling in, was as a salad in first century A. D.. It was then cultivated for medicinal purposes. Its value in brewing became recognized in the twelfth century and this, probably, was of German origin. It was introduced into North America in 1629. In 1802, hop seeds and plants were brought to Australia for cultivation and the plant has been grown in Tasmania and Victoria ever since.

The hop belongs to the family Cannabinaceae. Its distribution is restricted to the temperate zone and the regions of commercial hop growing lie between north latitudes 43° and 54° in Europe, 38° and 51° in North America, and 37° S and 43° S in Australia.

The hop is a perennial dioecious plant, lasting many years. The root system of a fully developed hop plant is very large; within the soil it extends to a depth of 150 cm. or more, and laterally to a diameter of about 200 cm. This extensive root system enables the plant to take up very efficiently the huge amount of mineral nutrients and, in particular, water to support its rapid growth.

The base of the long, slender, climbing stem becomes swollen and remains living when the upper part of the plant is cut at harvest. This enlargement of the plant continues, and after a few years, a rootstock

consisting of stem and root tissue is developed at or just below soil-level. The numerous buds on the rootstock remain dormant during the winter and commence to elongate in early spring as the weather becomes favourable. Shoots then grow up in such a way that the apices rotate in a clockwise direction, enabling the vine to encircle the string set up for it, then the vine describes a simple helix on the string all the way up till the top wire. Lateral branches then develop from buds in the axils of the leaves on the main vine. Hop leaves are hairy on both surfaces and decussate with each pair of opposite leaves arising from the nodes on the main vine or lateral branch. The buds in the axils of the leaves of lateral branches and at the top of the main vine develop into flowers or burrs. The burr rapidly becomes cone-shaped and contains small yellow globules called lupulin gland situated along the central stalk and at the base of the petals. It is mainly this substance that contains those agents that are used in the manufacture of Beers, Stouts etc..

1.2. HOPS IN TASMANIA

Currently, about 75 per cent of the hops grown in Australia is in Tasmania, with a total of 810 hectares of 'Pride of Ringwood', located in the South (Bushy Park and Huon Valley, 328 ha.), Scottsdale (320 ha.) and Gunn's Plains (162 ha.). The gross value of hops was $6.9 million, some 6.5% of gross value for all crops in Tasmania (Anon. 1985). Largely mechanized harvesting commences from mid-late March according to season (in Victoria, from late February or early March). The base of the vine is slashed about half a metre above the ground, then the top of the vine as well. The upper parts are transported to the picking machine, leaving many fallen leaves, small branches, twigs and the basal part of

stems. The plant remains dormant after the harvest through the whole winter, from April to August. As spring progresses, the hop hills shoot out numerous vines some of which are selected and two or three of those selected are twisted around each of the three strings in a clock-wise direction. Under normal conditions, the vines grow very fast and are expected to reach the overhead wires (some 5.5-6 m from the ground) at about Christmas time. Then they start developing side shoots (laterals), giving flowers and finally hop cones. At about mid-March, cones are mature and ready for harvesting (Anon. 1975, Anon. 1987).

1.3. THE DISEASES AND PESTS OF HOPS

Like any other crop, the hop under cultivation has some chronic fungal and virus diseases and many invertebrate pests which all need certain control action to be taken every year. The following information on world-wide occurrence of pests and diseases is summarized mainly from Harris (1964), Moreton (1964).

1.3.1. The Major Fungal Diseases

The fungal diseases are the result of the penetration of the hyphae into a healthy hop plant, followed by the poisoning and disfiguring actions of the invading mycelium. Among fungal diseases, Downy Mildew, Progressive Wilt and Powdery Mildew are the most serious and widespread ones.

Downy Mildew (*Pseudoperonospora humuli* (Miyabe and Takahashi) G.W. Wilson) is a wet-season disease due to its semiaquatic habit and can only effectively persist in nature on the living hop plant as an obligate parasite. Infections on leaves result in dark-brown angular spots. The

infection of the flowers (burr) will inhibit cone formation entirely and later infection of maturing cones will cause them to become brown and unmarketable. Besides infecting the vine, the mycelium also commonly invades the rootstock tissues and overwinters there. The infected rootstock may be completely killed. Overall this disease may be regarded as a potential "killer". To protect the crop from this disease, periodic spraying or dusting with various fungicides are essential.

Progressive Wilt (*Verticillium albo-atrum* Reinke and Berthold) infects the hop either by direct mycelial invasion of roots in contact with infected debris or by means of minute colourless single-celled conidia. The fungus enters the hop plant roots from the soil, then penetrates into the vascular core and travels up into the annual-vine system or even as far as the leaf stalks and leaves. Two signs of its invasion are: (1) invariably, a uniform coffee-brown discoloration of the woody core of the vines from the base upwards, and (2) frequently, a characteristic " tiger-stripe" wilting of the leaves, also starting with the basal ones. The outbreak of this disease is typically short, sharp, and completely fatal. The vines and leaves may become withered and dead very soon after infection. The control measures of this highly infectious and severe disease are: (1) direct eradication measures, aiming at the elimination of the virulent fungus from the district of its origin, which includes routine plantation sanitation, soil disinfection by chemicals, and (2) indirect control by the production of acceptable wilt-tolerant varieties.

Powdery Mildew, or **hop mould** (*Sphaerotheca humuli* (DC.) Burr) is an obligate parasite. It infects and invades the surfaces of the vines, leaves, burr and cones, but not the perennial rootstock. Attack by this fungus rarely affects the growth of the hill but prevents the burr maturing and also considerably reduces the commercial value of the cones. The

infection appears as white, circular and powdery patches of mildew on leaf surfaces, burr and cones. Control measures include the normal cultural operation of leaf "stripping", spraying and dusting of sulphur and varietal resistance.

1.3.2. The Virus Diseases

Infection by Viruses, unlike those due to fungi which can themselves be seen, can only be detected visually by the symptoms they cause on the host plant. More often, some virus diseases are caused by associations of two or more viruses. Most virus diseases are spread by animals, from man to insects, mites and eelworms. Three main viruses or virus group on hops can be distinguished: (1) hop mosaic virus, commonly fatal in its effect; (2) hop nettlehead virus which weakens but normally does not kill the hop plant it infects; and (3) hop split leaf blotch virus, causing leaves to become distorted, then split, withered or even death. Two common control measures for these diseases are: (1) to ensure that the planting material comes from a source free of the diseases, and (2) once recognized, the infected hill should be completely grubbed, removed and burnt.

1.3.3. Invertebrate Pests

These pests can be described under two categories: (1) attacking the foliage and shoots, and (2) living in the soil and infesting the roots and crown tissues.

Among the first group, there are such minor insects for which control measures only have to be applied occasionally such as potato aphid (*Macrosiphum euphorbiae* Thos.), hop capsid (*Calocoris fulvomaculatus* Deg.), hop leafhopper (*Euacanthus interruptus* L.),

common earwig (*Forficula auricularia* L.), rosy rustic moth (*Gortyna micacea* Esp.), hop flea beetle (*Psylliodes attenuata* Koch), hop strig midge (*Contarinia humuli* Tolg), springtails(*Mydonius nivalis* L.), and slugs. The most important one is the damson-hop aphid, followed by two spotted spider mite.

Damson-hop aphid, *Phorodon humuli* Schr., is the most serious insect pest of the hop in other parts of the world, calling for regular applications of insecticides either as foliar sprays or soil drenches, as many as ten sprays per season in Europe. It does not occur in Australia. It can severely stunt growth by colonizing the whole plant and feeding on the undersides of the leaves, render the cones valueless, and even transmit the hop mosaic virus and split leaf blotch virus if left unchecked. It overwinters as eggs on the twigs of *Prunus* spp.. After one or two generations of wingless female aphids, winged female forms develop, these then disperse to hops where they may produce several generations during the summer. A return flight to the winter hosts occurs in Autumn where winged females produce wingless females, which mate with the males and lay their winter eggs.

Two spotted spider mite (TSSM), *Tetranychus urticae* Koch, is a well-known pest on almost every crop and is one of the major pests of the hop all around the world. Its reproduction rate is very high, so that under favourable conditions heavy infestation may develop, leading to silver mottling and browning of the leaves, and later the cones, through constant sucking of the sap, with general weakening of the plant and severe loss of the crop. The mites pass the winter as adult females which shelter in protected places. When spring comes, the overwintered females leave their hibernation sites, climb the vines and feed on the lower surface of the

leaves. A succession of several generations may occur during the summer. As autumn approaches, the mites cease reproduction, move to ground and seek hibernating sites.

Among the second group which damage the roots and crown tissues and further weaken the vine, there are hop root weevils (*Epipolaeus caliginosus* F.), wireworms, which are the slender yellow larvae of the click (elatrid) beetles (*Agriotes sputator* L. and *A. obscurus* L.), larvae of three common chafer beetles-cockchafers (*Melolontha melolontha* L.), summer chafers (*Amphimallus solstitialis* L.) and garden chafers (*Phyllopertha horticola* L.), ghost swift moths (*Hepialus humuli* L.), leatherjackets (larvae of craneflies such as *Tipula paludosa* Meig.), millipedes, eelworms etc.. Pests in this group normally do not cause much damage, as outbreaks occur only rarely.

1.4. THE MAJOR HOP PEST IN AUSTRALIA

The status of hop pests in Australia is quite unique. Those major pests affecting hops in the Northern Hemisphere, such as downy mildew (*Pseudoperonospora humuli* (Miyabe and Takahashi) G.W. Wilson), progressive wilt (*Verticillium albo-atrum* Reinke and Berthold), powdery mildew (*Sphaerotheca humuli* (DC.) Burr) and damson-hop aphid (*Phorodon humuli* Schr.), do not occur. Consequently, the cost of pest control is considerably lower than that experienced in Europe and North America. In both Victoria and Tasmania the most significant pest is the Two Spotted Spider Mite (TSSM), *Tetranychus urticae* Koch, which normally requires at least one miticide application each growing season. For this pest, excellent control has been achieved with cyhexatin (=Plictran, tricyclohexylhexahydroxystannane), an organo-tin acaricide,

for more than ten years (Anon. 1986). However, as the chemical residuals on hop products are of increasing concern to brewers through a possible teratogen effect, cyhexatin was withdrawn and deregistered in 1987. Two new miticides, Omite and Apollo, were subsequently registered in Tasmania to control the TSSM. But it has been shown that these two new miticides are not as efficient as cyhexatin and also, the cost of applying them is much higher than that of applying cyhexatin.

Under such circumstances, it is quite obvious that there is the necessity to obtain more knowledge about TSSM and its relationship to the hop host plant so that an integrated pest management strategy that minimizes the reliance and cost associated with miticides can be put into practice.

1.5. THE AIMS OF THIS STUDY

The aims of this study are to:

1. establish the basic biology, phenology and ecology of TSSM on hops in Tasmania;
2. assess the effect of spraying with either Lime-sulphur or Summer-oil on TSSM numbers during the hop growing season;
3. evaluate the effect of introducing the predatory mite *Phytoseiulus persimilis* (Athias-Henriot) into hop fields and monitor the biology and ecology of this predator and a native predacious mite, *Amblyseius longispinosus* (Evans);
4. assess the damage caused by TSSM on hop yields and
5. judge the practicability of an integrated pest management programme.

CHAPTER TWO

LITERATURE REVIEW

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2.1. GENERAL BIOLOGY, ECOLOGY AND CONTROL OF *TETRANYCHUS URTICAE* KOCH

2.1.1. Taxonomy

The taxonomic status of Two Spotted Spider Mite (TSSM), *Tetranychus urticae* Koch, was historically confused because of the large number of closely-related species, the wide range of host plants and the different opinions among taxonomists. Among the list of synonyms there are more than 50 different names, such as *T. bimaculatus, T. attanticus, T. altheae, T. telarius,* etc. which were commonly used. The present taxonomic status of TSSM is generally accepted as :

CLASS	Arachnida
SUBCLASS	Acari
ORDER	Acarina
SUBORDER	Trombidiforms
SUPERFAMILY	Tetranychoidea
FAMILY	Tetranychidae
GENUS	*Tetranychus*
SPECIES	*urticae* Koch 1936

(Unwin 1971, Vrie *et al.* 1972, Jeppson *et al.* 1975 and Kuang 1986).

2.1.2. Life Cycle, Development and Reproduction

TSSM develops through the stages of egg, larva, protonymph,

deutonymph and adult. The round egg is translucent and about 110 µm. in diameter, with a smooth surface (Crooker 1985 and Kuang 1986). The duration of the egg stage is variable depending on temperature, humidity, host plant and other factors. On a given host, the embryonic period varies, mainly with temperature (Crooker 1985).

Larvae, protonymphs and deutonymphs, the three active and feeding stages, are respectively each followed by an intervening period of quiescence called protochrysalis (or nymphochrysalis), deutochrysalis and teleiochrysalis. During these inactive stages, the mite keeps still on the leaf surface and undergoes ecdysis and other physiological changes. The larvae have three pairs of legs and the subsequent stages four pairs. Sexual dimorphism is first apparent in the deutonymph stage (Unwin 1971, Jeppson *et al.* 1975 and Crooker 1985).

Table 2.1. Developmental time in days for *Tetranychus urticae* Koch at 21°C.

	Active	Quiescent	Total
Larva			
Male	1.5	1.3	2.8
Female	1.5	1.2	2.7
Protonymph			
Male	1.0	1.3	2.3
Female	1.3	1.2	2.4
Deutonymph			
Male	1.0	1.4	2.5
Female	1.5	1.4	2.9

From (Herbert 1981)

As seen from Table 2.1., it is apparent that the females take longer to

develop than males and this may be a general feature of spider mite development (Herbert 1981). The adult females are about 0.5 mm in length and oval-shaped. Males are slightly smaller and slender, more active and with a more pointed abdomen. Both sexes are variable in colour, usually with shades of green, yellow, or red, and characteristically bearing two large darker pigmented shoulder spots to which their name is ascribed (Fenner 1962, Davidson and Peairs 1966, and Unwin 1971).

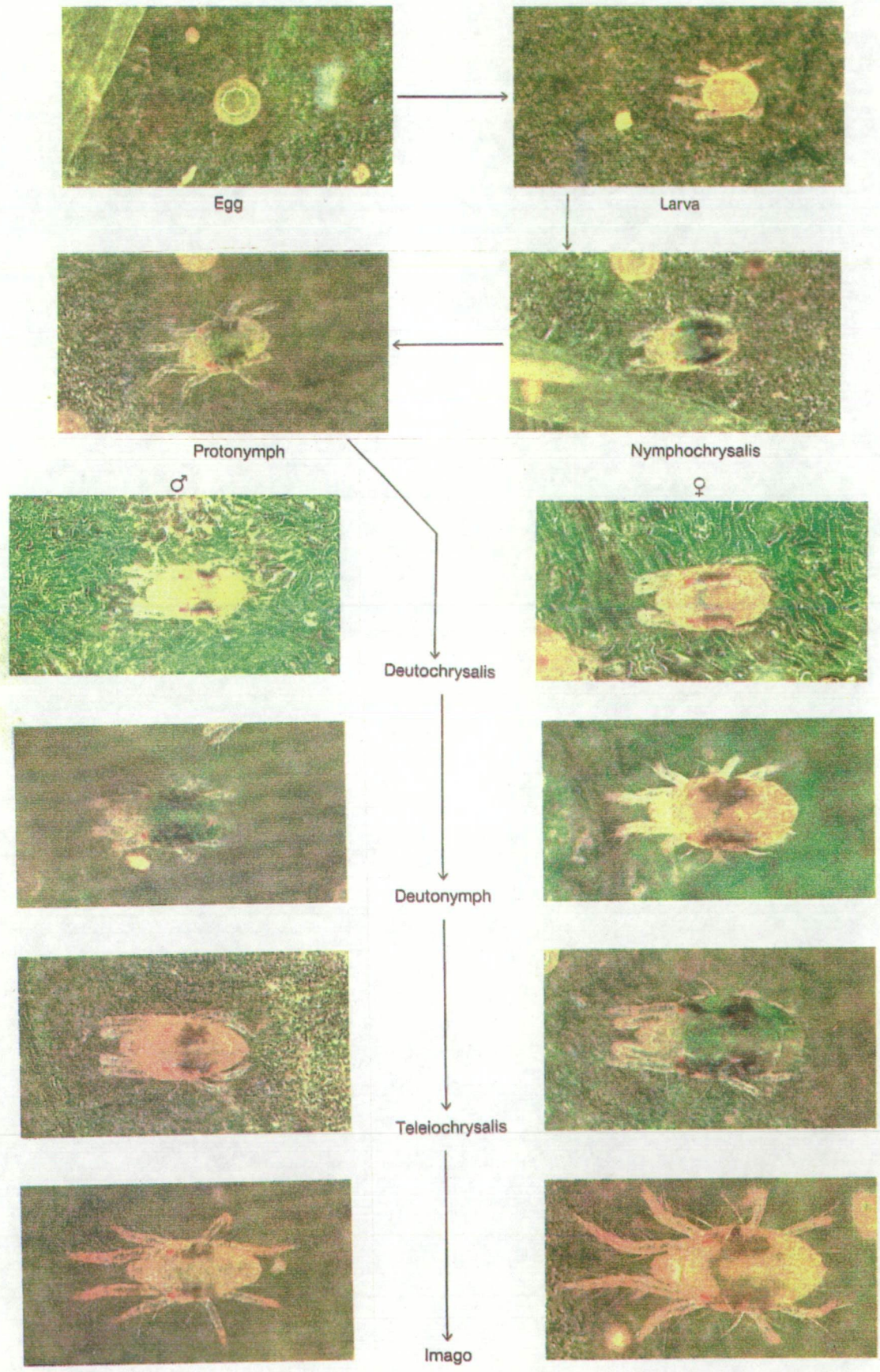
The developmental stages of TSSM are presented in Plate 1 (from Zoebelein and Kniehase 1985).

The mating process is usually accomplished immediately after the last molt of the female. The firstly moulted males detect the teleiochrysalis, perhaps guided by silk webbing and a sex attractant, then remain waiting until the exuviae are cast, or may even aid in removing it. Often, there are more than one male waiting. The male crawls head first under the posterior end of the teneral female and arches the end of its abdomen upwards to accomplish coupling (Jeppson *et al.* 1975 and Cone 1985).

Normally a female only mates once which will provide her with enough sperm for life, and when there are multiple matings the sperm of the first male takes precedence. The first eggs are laid within three days of adult emergence, i.e., the preoviposition period is about 1 to 3 days (Helle 1967 and Unwin 1971).

Reproduction, involving both sexes, is based on arrhenotokous parthenogenesis, that is, virgin females give only male offspring and fertilized females produce both females and males. The chromosome number in males is haploid (n=3), and in females diploid (2n=6). Thus the term haploid-diploidy is ascribed. It is clear that those eggs escaping

Plate 1. The developmental stages of TSSM (*Tetranychus urticae* Koch).



fertilization are male determined. Only those fertilized eggs are female determined. There are always more females than males in a TSSM population. It would be considered as 'normal' for a sex ratio of 1 male to approximately 3 females (Unwin 1971, Helle and Pijnacker 1985).

Under a diurnal temperature cycle of 15.0 to 28.3°C, the females deposit an average of 2.4 eggs per day for 15.7 days (Laing 1969). An average figure of 70 eggs per female over a two-weekly period may be suggested as representative of this species (Unwin 1971).

The complete life cycle may occupy as little as 7 days or as much as 26 days under summer field conditions. In temperate Australia, a life cycle duration of 12-13 days is usual in midsummer (Fig. 2.1.). Population increase is favoured by hot, dry weather and checked by cool, wet weather. Under normal summer conditions, very high populations can be attained in a relatively short time so that outbreaks occur (Davidson and Peairs 1966, Unwin 1971).

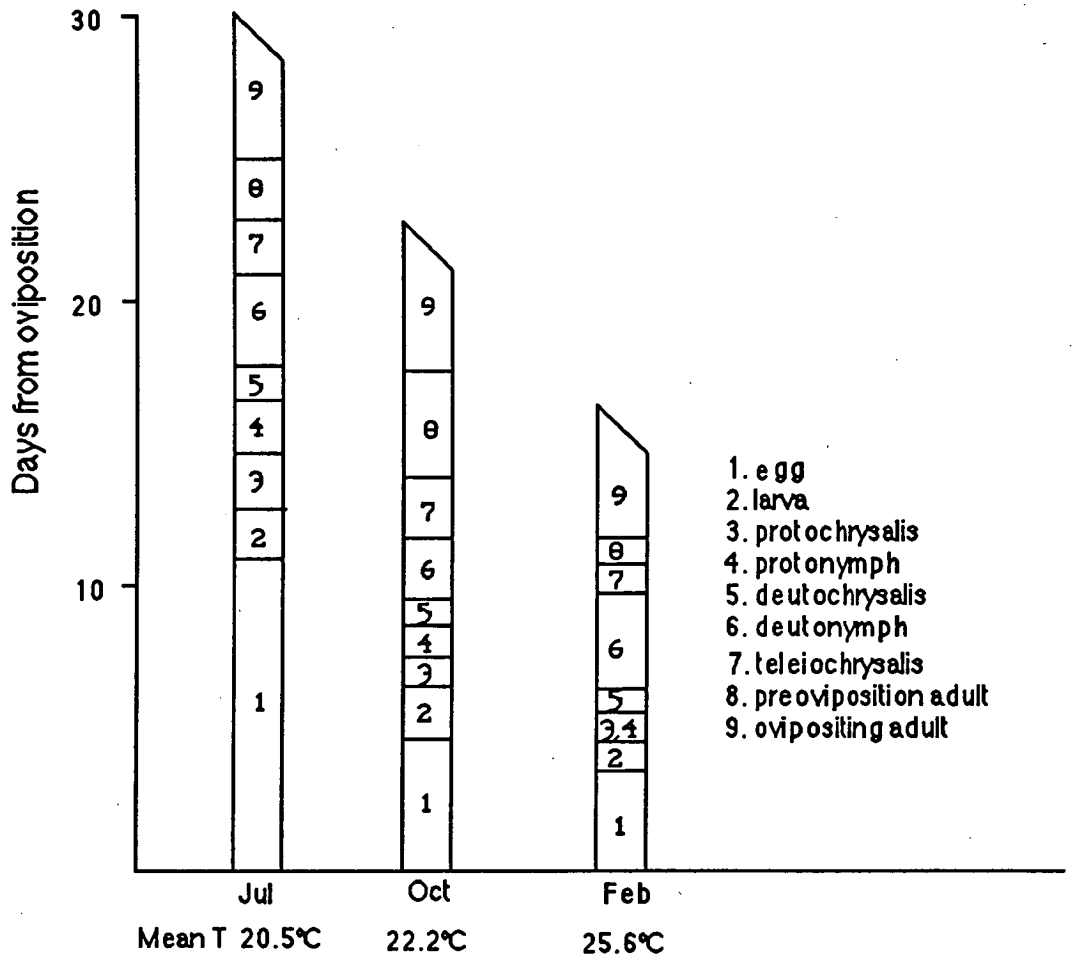
There are several or even up to twenty generations occuring in the field every year (The number of the generation varies largely with weather and food resources) and these overlap so much through most of the active season that all life stages are present at the same time (Davidson and Peairs 1966, Vire *et al.* 1972, and Kuang 1986).

2.1.3. Diapause

TSSM population in the field has two different colonies: a summer colony and a winter colony. All damage is caused by the summer forms, while the winter forms are those in hibernation or diapause. In late summer or early autumn, with the onset of shorter day lights, decreased temperatures, and a less favourable food supply, the females of the

summer colony stop feeding and laying egg. They leave their host plants, become yellowish orange, and hibernate on the ground under leaves, in

Fig. 2.1. Effect of glasshouse temperature on duration of *T. urticae* life cycle stages at N. S. W. (From Unwin 1971).



cracks and crevices, or in other protected places (Jeppson *et al.*1975); whereas all the males die. The overwintering adult females, which were fertilized before going into diapause, differ from the summer females mainly in having a bright orange colour and in the arrest in feeding and

oviposition, also in other morphological, physiological and behavioural aspects (Veerman 1985).

2.1.4. Dispersal

TSSM has well-developed dispersal mechanisms which enable its population to spread throughout and fully exploit individual host plants as well as to spread to other areas. In addition, dispersal is an important mechanism of escape from natural enemies (Kennedy and Smitley 1985).

In early spring, the overwintered females seek out their oviposition sites on the new season's foliage. Subsequent generations migrate throughout the remainder of the crop (Unwin 1971). The mites disperse through two different ways: crawling, which is a common means of intra-plant dispersal and sometimes inter-plant, and aerial dispersal, which occures mainly between plants (Kennedy and Smitley 1985).

There is a tendency for teneral (mated) females to emigrate from the leaf on which they developed, regardless of the population density on that leaf, while the ovipositing females show less tendency to emigrate from a leaf. In the early stages of infestation, there is no migration from the host. When a host becomes heavily infested (i.e., all the apical foliage of the host plant has been infested and becomes chlorotic), the mites begin to abandon the host. Normally, a gradual developing infestation suggests the movement by walking. Movement by wind dispersal would be more likely to be responsible for a sudden infestation (Hussey and Parr 1963, a; Kennedy and Smitley 1985) .

2.1.5. Webbing

TSSM can produce silk thread to form a web, which confers a number

of advantages upon mites. Thus maturing mites utilize their webs for various courtship-associated purposes. While the pre-moulting last female nymph spins the silken cover under which it will transform, it also secretes a sex pheromone. Modified by the web, males movement towards the moulting nymph becomes more linear. Males may spin a web over the female web. Therefore, the web becomes a physical contact between the sexes. A very close relationship between the walking activity and the amounts of webs spun was demonstrated. It was postulated that mites spun silk threads whenever walking. When dispersing from heavily infested hosts, the mites in glasshouse can form silk ropes with which they form a silken ball, then start dropping off from the apices of the host plants. As soon as teneral females arrive at a suitable site, they begin to web as they start feeding. Emergent larvae and nymphs also spin. So a covering of silk is gradually formed on the substrate which increases as the mite number increases to serve as a nest for the colony. Once established, mites tend to remain within their territory as defined by the web. The webbing protects mites from being blown off by wind and wetted or washed by rain and from various natural enemies as well (but specific predators appear to be attracted to and unhindered by the silk). Further webs may serve as a protective canopy against pesticide particles, holding spray droplets and dust particles away from the mites (Gerson 1985, a).

2.1.6. Life Type

The mode of life of the spider mite can be classified into life types, mainly through web characteristics, as spider mites have evolved different behavioural patterns in response to the web structure and design.

In order to characterize the life of the spider mite with respect to the

patterns of webbing , some items are selected as criteria. According to these items, it is possible to divide the life patterns of many tetranychines into three main groups called 'life types' and symbolically indicated by LW (little web type), CW (complicated web type) and WN (web nest type). Every life type includes several subtypes.

TSSM is classified to have a life type of CW-u which is characterized by complicated webs, a three-dimensional and irregular structure of silk threads. The mites tend to walk on the web, and deposit their eggs and pass their quiescence on the leaf surface under the web. Also the web is used as sites where the mites deposit their faeces and this may prevent the inhabited surface from deterioration through the accumulation of faeces. When the population density becomes high, numerous faecal pellets, eggs and cast skins may accumulate on the complicated web threads.

From the relationships between phytoseiid efficiency and prey webbing patterns, it is noted that there are close interactions between spider mite life types and the behaviour of specific phytoseiid mites (Saitô 1985).

2.1.7. Feeding and Damage

The following information is mainly summarised from Jeppson *et al.* (1975), Sances *et al.* (1979).

TSSM is among the most common world-wide plant pests, with a record of more than 150 hosts of agricultural crops and ornamental plants, and one of the most destructive, often killing the host plant very rapidly. The mite mainly feeds on leaves, sometimes also on other plant parts like fruits, flowers, fruit spurs or tips of shoots etc., to cause mechanical, chemical, and physiological disturbance and damage

TSSM prefers to colonize on the upper leaf surface of some plants and

the lower surface of others, but in cases of heavy infestation they inhabit all plant surfaces. Normally, they prefer young leaves, but in well established colonies, the older leaves become heavily inhabited as well .

The symptoms are small, light coloured punctures which then develop into irregularly shaped white or greyish-coloured spots. In severe cases leaf burning and defoliation can occur. Different host plants may show differences in the severity of symptoms after feeding by this species.

TSSM feeds by penetrating the plant tissue with its sharp stylet and removing the cell contents. The depth of damage is related to the length of the stylets, the feeding time and the population density, and also the host plant characteristics. On strawberry leaves, the depths of injury are approximately 85, 90 and 118 μm. at mite densities of 144, 732 and 1383 mite-days/leaflet respectively; low density populations mainly damage the spongy mesophyll tissue with slight injury to the lowest parenchyma cells; while higher population densities increase the sphere of damage with more severe injury to the palisade parenchyma. It is estimated that TSSM could exhaust about 18 to 22 cells per minute in feeding. The feeding activity of the mites not only causes the cells, which are directly damaged, to lose either their chloroplasts or to have their chloroplasts coagulated. Destruction of chloroplasts in cells adjacent to the damaged cells may occur also.

A very important change which occurs in the epidermal cell layers following damage is the disturbing effect on the function of the stomatal apparatus. On strawberry leaves, the destruction of the stomatal apparatus was not caused by mechanical damage to the epidermal layer, but resulted from the injury to the spongy parenchyma. Dehydrated cells of this tissue cause a lack of turgor in the guard cells. This failure of the

guard cells results in the closing of the stomata. About 60% of the stomata is closed in damaged strawberry leaves while the unaffected leaves only have about 30% of the stomata closed. When stomata are closed, CO_2 uptake would be reduced .

It was also demonstrated that the water balance of mite-attacked leaves was greatly disturbed. Damaged peppermint leaves transpired less during the day than undamaged leaves; however, in the absence of light transpiration was 3 times higher in the damaged leaves as compared to undamaged leaves. Consequently, water stress was induced. It is also possible that injected saliva may have some influence on photosynthesis by exerting an influence on the activity of photosynthesic enzymes and causing changes in carbon pathways.

Because meristematic tissues are not present in leaves of crop plants, the possibility of leaves recovering from spider mite feeding is unlikely. Therefore, reduction in functional photosynthetic area caused by spider mite feeding would be permanent and could only be compensated for by the production of new foliage by the plant, and this may occur only at low level of infestation.

As a consequence of damage to plant tissue and disturbance of plant physiological processes, changes in growth, flowering and yield may be commonly observed, among which the most common phenomenon is a retardation of the growth of all organs and a reduction in ultimate production of damaged crop plants.

However, not all host plants show identical reactions or intensity of reaction to mite feeding due to the difference between host plants. Furthermore, it should be realized that mite-host plant relationships are mutual in effect. There are not only mechanisms favouring mite development, other reactions may be considered as defense mechanisms.

2.2. CONTROL OF TSSM

2.2.1. Natural Predators

Among the natural enemies of TSSM, there are insects, spiders, predaceous mites and disease-producing pathogens. The predatory mites of the family Phytoseiidae have received the most recent and widespread attention. Certain groups of insectan predators and pathogens have been fairly widely studied, but seldom the spiders (McMurtry *et al.* 1970).

2.2.1.1. Predaceous mites

Phytoseiids

These mites belong to the family Phytoseiidae of the suborder Gamaside, superfamily Phytoseioidea. Phytoseiids are free living, terrestrial mites and occur on foliage, bark, and humus in all parts of the world. Most of them prey on tetranychids and other small organisms. These mites are approximately the same size as tetranychids but of very different structure (Chant 1985). They pass through the same developmental stages as do the tetranychids. Their life cycle may be shorter than that of tetranychids under comparable conditions. Their fecundity is generally lower than that of their prey. An average of about 2 eggs/female/day may be the maximum productivity for most species, but daily productivity together with the total number of eggs laid per female is dependent on climatic factors and food supply (Jeppson *et al.* 1975). Reproduction involves both sexes. Pseudo-arrhenotoky is the mode of reproduction in phytoseiids. In this type of arrhenotoky, mating is a prerequisite for oviposition; both males and females develop from fertilized eggs; however, during early development,

one set of the chromosomes may be eliminated, leading to haploid males (Schulten 1985). Phytoseiids live longer than their tetranychid prey (Sabelis 1985, a). Only mated females overwinter in temperate climates. In warmer climates they are active throughout the year (Jeppson *et al.* 1975).

Phytoseiids show a great diversity in feeding habits. Apart from prey, pollen of various kinds of plants may serve as alternative food for certain phytoseiids. Species like *Phytoseiulus persimilis* Athias-Henriot have reached such a degree of specialization that they depend on tetranychid mites for food. Some of the mite predators are rather specific as to the mite species upon which they feed, such as *Amblyseius fallacis* Garman, which readily feeds on *T. urticae* and another species, but not on the European red mite, *Panonychus ulmi* Koch, or the brown mite, *Bryobia rubrioculus* Scheuten. It has been shown that the maximum number of prey consumed by *P. persimilis* decreased in the following order (almost independent of the developmental stage of the predator): eggs, larvae, protonymphs and deutonymphs. In some other cases, the egg is more commonly consumed by predatory mites than the other stages of spider mites (Jeppson *et al.* 1975, Overmeer 1985, and Sabelis 1985, b).

Other Acarine Predators

Non-phytoseiids predatory mites include some species in the families Anystidae, Bdellidae, Cheyletidae, Erythraeidae, Stigmaeidae, Tarsonemidae and Tydeidae, among which the Stigmaeidae are the most important, with the other groups only having a minor effect on spider mites. This family is distributed throughout the world and is often characterized by its distinctive dorsalshield configurations (Gerson 1985, b).

2.2.1.2. Predaceous insects

The information in this section is largely drawn from Jeppson *et al.* (1975) and Chazeau (1985).

Among the predatory insects, several species prey on spider mites. They belong to Coleoptera, Dermaptera, Diptera, Hemiptera, Neuroptera and Thysanoptera. The degree of their adaptation to the prey, as well as their efficiency in controlling mite populations, varies with the species and the environmental conditions.

Coleoptera

Two families in this order contain important mite predators, the Coccinellidae and Staphylinidae. The most important genus is *Stethorus* Weise of the coccinellids. They are effective predators only of mites, relatively small but remarkably well adapted to living and searching for prey in the habitats of plant-feeding mites. Their development may be completed in two weeks under the most favourable temperature conditions, a slightly longer time than it is required for the development of most plant feeding mites. In areas of temperate climate, these beetles hibernate as adults and can have 2 or 3 generations per year. The adults can fly actively and aggregate on mite colonies. They chew and eat the whole mite and they are capable of consuming large number of mites. Capacity to aggregate on mite infestations and to disperse when prey becomes scarce are positive characteristics of these predators. However, they need a minimum population density of mites in order to colonize infested plants successfully and for this reason these beetles rarely exert a suppressive effect on mite population before economic injury levels are reached.

The genus *Oligota* Mannerheim of the family Staphylinidae live in

decaying plants or in fungi, in stored products, under the bark of trees where they may either prey upon mites and small insects or feed on tiny dead arthropods. They are not considered effective mite predators, but they aid other predators in regulating mite populations.

The occurrence of other coccinellids is irregular; also tetranychids never constitute the favourite prey for these beetles; so they are not primary predators of spider mites either.

Dermaptera

Earwigs are usually omnivorous. There was only one case of predation by *Labidura riparia* Pallas (Labiduridae) on *T. urticae* reported in South Africa in 1974; still the number of prey consumed by juveniles was very low (< 5 mites per day) and adults seldom attacked spider mites.

Diptera

Some larvae and adults of the brachyceran flies prey on spider mites. But as they are aphidophagous or non-specialized predators, their effectiveness in against spider mites is probably not very important.

Hemiptera

The majority of Hemiptera which attack spider mites belong to two families, the Anthocoridae and Miridae; but few, if any, appear to be specialized predators of mites. Some bugs in the families Nabidae and Lygaeidae are general predators that consume mites during their feeding, but obviously they are of secondary importance.

Neuroptera

Insects in this order are mainly general feeders and their prey may also include mites. The most active predators of spider mites belong to the families Chrysopidae and Coniopterygidae. They are useful predators at low population densities of mites owing to a very high searching capacity.

Chrysopa carnea Staphens, a general feeder, can influence European red mite populations in some districts together with other predators in Europe and North America.

Thysanoptera

Three families, Phlaeothripidae, Aeolothripidae and Thripidae, of this order contain a small number of species which prey on spider mites. These thrips do not use their legs to grasp prey. Therefore, eggs of spider mites are completely consumed, but other instars of the mite are only partially sucked; this behaviour increases the number of prey killed, and so improves predation efficiency. At times, these predaceous thrips may reduce mite populations rapidly.

2.2.1.3. Pathogens

The following paragraphs in this section are mainly summarised from van der Geest (1985).

Pathogens of spider mites are only known from the viruses and fungi, some of which have potential as control agents of phytophagous mites, or contribute to the natural regulation of spider mite populations.

Virus Diseases

Most infected mites contain, in the mid-gut, birefrigent and irregular crystalline bodies. Therefore, the frequency of these crystals in mites is a measure of the incidence of the disease in a population. The virus disease is common in natural populations of the citrus red mite in California and Arizona, where it can reduce large populations of mites to a low level and sometimes makes application of acaricides unnecessary.

Fungus Disease

The natural occurrence of entomogenous fungus diseases has been

observed in several species of spider mites. Sometimes they may play an important role in the regulation of some spider mite populations. A few reports have indicated that very high percentage mortality of *T.urticae* has been caused by entomogenous fungi under natural conditions. But, in general, the incidence of infection by fungi and germination of the spores are strongly dependent on climatic conditions and in particular, a high relative humidity (up to 99%). This fact makes the application of fungal diseases against spider mites very limited.

2.2.1.4. Spiders

Spiders have been reported to feed on spider mites as general feeders. It was noted that many more spiders were present in unsprayed, as compared to sprayed, apple orchards in southern England. But more quantitative work is required to evaluate the importance of spiders in reducing the spider mite populations (Gerson 1985).

2.2.2. The Development and Control of TSSM in Hops

It is known that spider mites do not commonly cause widespread damage in natural or semi-natural environments little influenced by man. But the mite has long been considered a potentially severe pest of a wide variety of major food and fibre crops, and of ornamentals, especially after World War II. The reason for its enhanced status as an economic pest is generally considered as: A. the improved ability of host plants to support large mite populations due to (1) the development of extensive areas of monoculture, which can provide vast food supplies for the mite and (2) the improved nutritional status of many crops—it is well known that better crops breed more and healthier mites;

B. the weakening or disappearing of the regulation of natural predators and diseases resulting mainly from the extensive use of broad—spectrum pesticides which have more adverse effect on the natural enemies than on the mite, and also from the limiting effect on the reservoirs of mite enemies owing to the conditions of monoculture;

C. the applications of chemicals which may, directly or indirectly, stimulate the natural mite populations by increasing fecundity and survival rates;

D. the development of the resistance to many widely used pesticides (Unwin 1971, van de Vire *et al.* 1972, Jeppson *et al.* 1975, Flint and van den Bosch 1981).

2.2.2.1. The development of pest control

Much of the information presented here is summarised from Flint and van den Bosch (1981).

Pest control is defined by Jeppson (1965) as the regulation of pest populations so that they remain below levels which adversely influence, economically, the quantity or the quality of the product. Control actions against pest became necessary soon after the development of agriculture. By the turn of the nineteenth century, five major approaches to pest control were well established: (1) biological control, (2) mechanical and physical control, (3) cultural control, (4) chemical control, and (5) use of resistant varieties. A sixth approach, legal control, through the use of inspections and quarantines to prevent the entry and spread of pest-infected materials, was first established in the United States in 1912. Pest control practice today still relies almost entirely on the utilization of methods in those first five categories.

Chemical Control

The greatest revolution in twentieth century pest control was the development of the synthetic organic pesticides, namely DDT and organophosphates. These new pesticides were toxic to virtually every pest, and the application of them soon became a common procedure in just about every agricultural crop and, subsequently, in urban and recreational areas as well. Unfortunately, problems associated with the heavy dependence on chemical control began to arise, and these problems were of an ecological--biological nature. The earliest hint of impending disaster was the development of resistance to the insecticides by some major pests. By 1965, 75% of the most serious agricultural insect pests in California had developed resistance to at least one major insecticide, and several had developed resistance to two or more materials.

Another consequence was the target pest resurgence, in which case the immediate effect of the treatment is a strong reduction of the pest but an even greater destruction of its natural enemies, permitting a rapid resurgence of the former to damaging abundance. A third problem was induced secondary pest outbreaks, that is, the chemical treatment effectively reduced the main pest as well as many natural enemies, but had little effect on a minor pest. Subsequently, the formerly minor pest emerges as a new major pest. A fourth problem resulting from the use of insecticides was environmental contaminations. Pesticides have been widely applied and they drift via wind and water to almost everywhere in the environment.

However the use of chemicals to kill pests of all kinds has been a major factor in increasing the productivity of modern agriculture. There is no doubt that pesticides will continue to be the most important defence

against pests that suddenly or unexpectedly break through the economic threshold as there is simply no other forms of control that are so effective under such conditions (Cox and Atkins 1979).

Cultural Control

Cultural controls are modifications of management practices that make the environment less favourable to pest reproduction, dispersal, and/or survival. The design and implementation of cultural control tactics require a good knowledge of crop and pest biology, ecology and phenology. Such tactics are generally designed to prevent pest buildup rather than relieve an already existing pest problem. Accordingly, timing is critical to the success of many cultural controls. Hundreds of cultural control techniques have been practiced in all areas of pest management. The most common ones are: sanitation, crop rotation, cultivation, trap crop, time of planting, harvesting practices, water and fertilizer management, and use of pest-free seed and planting stock etc..

Biological Control

Biological control is an attempt to reduce the average density of a pest population by the action of diseases, parasites, or predators (Krebs 1978). It involves the manipulation, conservation, and augmentation of specific kinds of appropriate natural enemies (Cox and Atkins 1979). It may be considered in three aspects: (1) existing, naturally occurring biological control, (2) the classic importation of natural enemies, and (3) enhancement of the environment to increase the effectiveness of natural enemies. As biological control, once established, is cheap, effective, permanent, and nondistruptive of other elements of the ecosystem, it has been attempted all around the world to control the most destructive pests, and various degree of success has been achieved.

Control Through Genetic Techniques

Control through genetic manipulation takes three forms: (1) the manipulation of the genetic makeup of the host plant or animal so that it is resistant to pest attack (host resistance), (2) the manipulation of the genetic makeup of a predator so that it is resistant to certain chemicals which are indispensable for regulation of pest population, and (3) the manipulation of the genetic makeup of the pest so that it cannot survive in the resource environment (autocidal techniques). All these three approaches have been widely investigated and are successful to some extent.

Mechanical and Physical Control

These controls are direct or indirect nonchemical measures that destroy pests outright or make the environment unsuitable for their entry, dispersal, survival or reproduction. They are distinguished from cultural controls in that these actions are taken specifically for pest control purposes and are not merely modifications of existing management practices. They may include such measures as temperature manipulation, light traps, pest barriers, screens, adhesive substances and water management, etc..

Integrated Pest Management

IPM is a complex concept, thus there exists a variety of its definitions. One brief definition to agriculture would be: the combination of as many suitable control methods as practical into an ecologically harmonized system designed to maintain pest populations below economic injury levels (Cox and Atkins 1979). IPM programme do not include eradication of any species already existing in the system. The main prerequisites in setting up an IPM programme are: (1) a full understanding of the biology,

physiology, ecology and phenology of the crop, the response of the crop plant to stress, and the effect of the physical environment, various management practices and the toxic chemicals on the crop; (2) an accurate identification of the key pests and a full understanding of their biology and ecology, their damage and economic status and, in particular, the weak links in the life cycle; and (3) identification of the key environmental factors, the methods and materials that individually and in combination will help to suppress permanently or restrain the pest and potential pest species. A wide range of IPM programs has been carried out in various pest of the world. Many of them have been impressively successful.

2.2.2.2. The control of TSSM on crops

Since TSSM is the most polyphagous species of the tetranychids, a great number of investigations have been conducted on the control of this species in various crop plants by using all possible measures.

Chemical control by a variety of insecticide and miticides can reduce mite populations to very low levels, therefore, they are very efficient and almost indispensable for controlling mites on many vegetables, ornamental plants, fruits and other economic crops both in the greenhouse and outdoors. As mentioned before, chemical control is still the most important and commonly used method, the problems resulted from using chemicals are: (1) resistance developing in more and more mite strains on different crops; (2) the detrimental effect on native or introduced predators; and (3) the probability of harmful residues remaining on crop products (Cox and Atkins 1979).

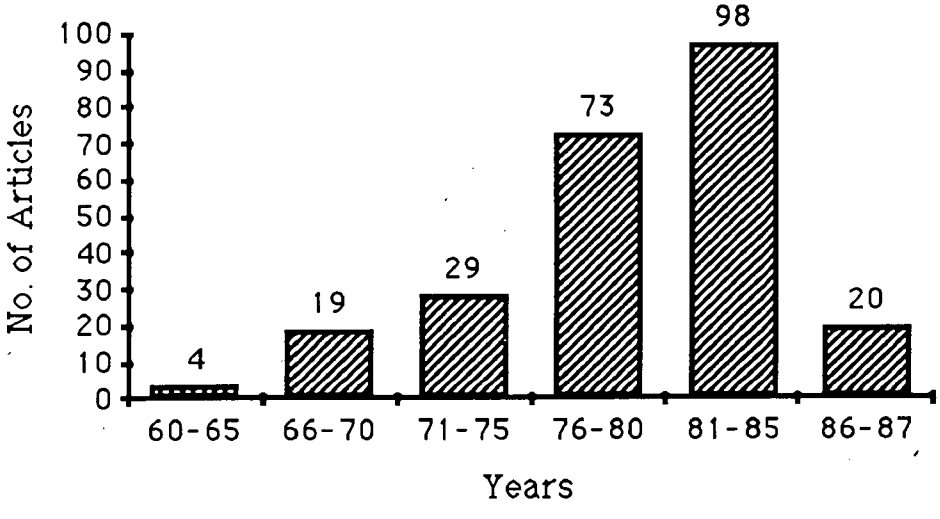
The emergence of artificially manipulating natural enemies to control

T. urticae on various crops was largely initiated by the recognition of the potential to control TSSM by the predacious mite *Phytoseiulus persimilis* (Athias-Henriot).

From the early 1960s', the use of *P. persimilis* to control *T. urticae* has spread quite rapidly to almost all parts of the world. Most cases of biological control of *T. urticae* have involved the predatory mite *P. persimilis* and they have been so successful that Caltagirone (1981) considered them as one of the landmark examples in classical biological control.

A survey in the Review of Applied Entomology reveals the rapid development, the wide range of the crop plants and the countries using *P. persimilis* and other natural enemies to control TSSM around the world (Fig. 2.2. and Table 2.2.).

Fig. 2.2. Articles on biological control programmes of *T. urticae* by various predators.



Compiled from *Rev. of Appl. Entomol. A.*1960 (48)-1987 (75).

Oatman *et al.* (1967) investigated the possibility of integrating mass release of *P. persimilis* with chemical applications for control of the TSSM on strawberries in California. Similar studies, aimed to integrate chemical control with biological control, have been conducted in many parts of the world. The use of miticides and natural enemies differs for each crop and country. Hamstead (1970) studied the integrating of some selected insecticides with a predaceous mite *Typhlodromus fallacis* on greenhouse

Table 2.2. Biological control programmes of *T. urticae* Koch

PREDATOR	CROP	LOCATION	REF. (Vol. No.)
Phytoseiulus persimilis	kidney bean	Canada	Chant, 1961 (50, 125)
	rose	USA	Smith et al, 1963 (51, 4901)
	cucumber	U. K.	Hussey & Parr, 1965 (54, 236)
			Legowski, 1966 (56, 753)
			Gould et al, 1969 (58, 1073);
			Gould,1980 (69, 4043)
	strawberry	USA	Oatman, 1965 (55, 971);
			Oatman et al, 1976 (65, 4959)
			McMurtry et al, 1978(67, 1087)
	cucumber	USSR	Begljarow, 1967 (58, 3401)
			Plotnikov, 1969 (61, 1187).
			Popov et al, 1980 (69, 287)
	cucumber	Switzerland	Vogel, 1969 (58, 2458)
			Freuler et al, 1980 (69, 286)
	white clover	Japan	Mori & Moriyama, 1970(59, 1350)
	bean	Romania	Iacob, 1972 (63, 1807)
	ivy	U. K.	Gould, 1971 (60, 3688)
	strawberry	U. K.	Simmonds, 1971 (60, 3681)
			Gould, 1978 (67, 4146)
			Port and Scopes1981 (70,3975)
	cucumber	Polland	Pruszynski et al 1972 (62,3579)
			Pruszynski et al 1984 (73,5689)
	rose	U. K.	Simmonds, 1972 (61, 5005)
			Samways, 1979 (68. 5735)
	cucumber	Finland	Markkula et al, 1972 (63,1718)
			Markkula, 1976 (66,2381)
			Raiskinmaki, 1980 (69,4052)
	tomato	Norway	Stenseth, 1973 (64,973)
			Stenseth, 1976 (66, 2380)
	cucumber		Stenseth, 1980 (69, 4058)

	cucumber	Sweden	Svenson, 1973 (64, 975) Jonsson, 1978 (67, 690)
	cucumber	Denmark	Berendt, 1980 (69, 4028)
	in glasshouse	Romania	Iacob, 1973 (64, 976)
	Capsicum and egg plant	Netherland	Woets, 1973 (64, 978)
	violet	England	Simmonds, 1973 (64, 908)
	tomato	England	Dixon, 1973 (62, 4917)
	cucumber	Bulgaria	Atanasov, 1974 (64, 1638)
	pomegranate	Bulgaria	Kumpelova & Gerova,1975 (64, 2252)
	tropical plants	Belgium	Malevez & Marechal, 1975 (64, 7520)
	cucumber, soybean, blackberry ,tomato	Japan	Mori, 1975 (64,3840)
	ornamentals	Polland	Pruszynski, 1976 (66,2369)
	tomato	U. K.	Gould, 1977 (66, 1376);
	rose	France	Pralavorio, 1976 (66, 2399)
Amblyseius gossipi	cotton	Egypt	Osman & Zohdi, 1976 (65, 2151)
Phytoseiulus persimilis	cucumber	Canada	Tonks & Everson, 1977 (66, 4015)
Entomophthora thaxteriana & E. virulenta	open & closed crops	USSR	Egina et al, 1977 (66,4654)
Bacillus thuringiensis	cucumber	USSR	Chilingaryan et al, 1977 (66, 794)
Entomophthora adjarica	medicinal plants	USSR	Tsintsadze et al, 1978 (67, 2072)
Phytoseiulus persimils	runner bean	GFR	Buhl, 1979 (69, 802)
P. persimilis	red clover	Japan	Mori & Saito), 1979 (68, 5921)
Amblyseius longispinosus *A. deleoni*			
Phytoseiulus persimilis	tomato	Finland	Raiskinmaki, 1980 (69, 4052)
	ornamentals	USA	Hamlen, 1980 (69, 1409)
	cucumber	Denmark	Berendt, 1980 (69, 4028)
	cucumber	Netherland	Koppert, 1980 (69, 2695)
	cucumber	USA	Lindquist, 1981 (70, 3425)
	chrysanthemum	Norway	Stenseth, 1981 (71, 517)
Phytoseiulus persimilis *Amblyseius potentillae* *A. bibens* *Metaseiulus occidentalis*	rose	Netherland	Sabelis, 1981 (70, 7202)
Phytoseiulus persimilis	cucumber	DDR	Adam, 1982 (71, 401)
M. occidentalis	peach	Australia	Field, 1982 (71, 6343)
M. occidentalis	pear & apple	USA	Hoy et al, 1983 (71, 7930)
Phytoseiulus persimilis	strawberry	Bulgaria	Atanasov, 1983 (72, 2947)
	vegetables and ornamentals	Greece	Koziraki, 1983 (72, 740)
	melon, sweet peppers,	Italy	Vacante, 1983 (72, 737)

	roses	Italy	Vacante & Firullo, 1983 (72, 4784)
	Capsicum	Bulgaria	Atanasov et al, 1983 (72, 5991)
	Capsicum	Polland	Pruszynski et al, 1985 (73, 5689)
	rose & cucumber		
	ornamental plants	China	Dong et al, 1986 (75, 363)
	cucumber	Czechoslovakia	Havelka & Kindlmann, 1984 (73,297)
Amblyseius longispinosus	strawberry	China(Taiwan)	Lo et al, 1984 (73, 4259)
Metaseiulus occidentalis	rose	USA	Field & Hoy, 1985 (73, 7734)
	apple	Australia	Bower, 1984 (73, 3402)
	rose	Australia	Clark & Buckley, 1984 (72, 4782)
Stethorus spp. and thrips	cotton	USSR	Kovalenkov, 1984 (73, 925)
Phytoseiulus persimilis	raspberry	New Zealand	Charles et al, 1985 (74, 1861)
	cucumber, aubergines	GFR	Frenz & Schlereth, 1985 (74,4615)
	runner beans, *Capsicum*		
Phytoseiulus persimilis	strawberry	France	Fournier et al, 1985 (74, 673)
Amblyseius chilenensis			
A. fallacis	apple	Canada	Bostanian et al, 1986 (75, 1809)
Metaseiulus occidentalis	rose	USA	Field & Hoy, 1986 (75, 4936)
Phytoseiulus persimilis	strawberry	New Zealand	Workman, 1986 (75, 2879)

Compiled from the *Review of Applied Entomology -Ser.A* 1960 (48)-1987 (75).

lima beans in the U.S.A.. In Australia, Walter (1976) tested the effect of five acaricides on *T. urticae* and its predator *Stethorus* spp. in an apple orchard. In England, Cross (1980) studied the combination of *P. persimilis* with aldicarb to control *T. urticae* on greenhouse chrysanthemums. Many other similar instances can be found in Woets (1976), Kowalska & Pruszynski (1976), Stenseth (1976), Pralavorio (1976), Samways (1979), Field (1982), Workman (1985) and Workman & Martin (1985).

Oatman (1970) investigated the integration of *P. persimilis* with some native predators (mainly *Typhlodromus occidentalis* Nesbitt and the six-spotted thrips, *Scolothrips sixmaculatus* (Pergande)) for control of the TSSM on rhubarb in California and found that the combined action resulted in an early reduction in the TSSM population. In New Zealand, Charles *et al.* (1985) studied the integrated control of *T. urticae* with *P.*

persimilis and *Stethorus bifidus* in commercial raspberry gardens.

Some other instances of integrated control of *T. urticae* can be found in situations where more than one pest are involved, thus the control of *T. urticae* is often associated with the control of other pests. Binns *et al.* (1971) found that in England when the aphid (*Aphis gossipi*) was effectively controlled on cucumber in glasshouses by 1-2 application of a chemical every seven days, difficulty was experienced in establishing *P. persimilis*. Barnes *et al.* (1978) studied the integrated control of pests in walnut orchards in California. Vacante and Nucifora (1987) reported the status of biological and integrated control of *T. urticae* on various vegetable crops and ornamental plants grown in greenhouses in France, Spain, Greece, Israel and Italy and discussed their future usage.

2.3. TSSM AND ITS CONTROL IN HOP YARDS

2.3.1. General Situation

Tetranychus urticae is the second most important worldwide pest on hops, the first being the Damson-hop aphid, *Phorodon humuli* Schrant. Through constant sucking of the sap, severe infestations of *T. urticae* cause silver mottling and browning of the leaves and, later, the cones become dry, red and brittle.

In regions where hops are grown, the TSSM exhibits differences in its pest status. Very often, the mite is killed by either the insecticides used to control the damson-hop aphid or fungicides used to control fungus diseases. In England, outbreaks of *T. urticae* are widespread only in hot, dry summers, while in central Europe they tend to occur more regularly. In the warm, dry interior valleys of the western U. S. A., the mite is the

the major pest of hops in most years (Cranham 1985). In West Germany, the acaricidal side effects of some fungicides were sufficiently effective on the mite to make the use of specific acaricides unnecessary (Kolbe and Kaspers 1968). A 6% average annual loss of hops was attributed to mites in the United States, for the period of 1951-1960 (Vrie *et al.* 1972). In Tasmania, a six percent loss in yield was estimated for the 1959/60 and 1978/79 seasons(Sutton 1982), and at least one miticide application is required every year for most crops in Australia.

The extensive use of organophosphate insecticides on hops to control the damson-hop aphid at first eliminated or greatly reduced *T. urticae,* which remained virtually absent for many years in English hop gardens (Cranham 1974). In 1968-70 in England and soon afterwards in Czechoslovakia, highly OP-resistant strains of *T. urticae* appeared on hops and these rapidly became widespread (Cranham 1985). Sittnra and Tarna (1979) reported the resistance of *T. urticae* on hops to OP's and this resulted in a reduction in the effectiveness of control measures and an increase in mite populations. Resistance to Dicofol, which was once a very effective acaricide, was widespread in English hops by 1976 (Cranham 1985). In Australian orchards, the resistance of *T. urticae* to Cyhexatin was detected in 1982 (Edge and James 1982). Zohdy (1972) studied the genetics of resistance to thiometon in two hop garden population of *T. urticae* and found that the resistance is inherited as a Mendelian dominant.

Generally, in commercial hop gardens, there occur predatory insect species of the families Anthocoroidae, Coccinellidae, Staphylinidae, Chrysopidae, Syrphidae and Cecidomyidae, with *Stethorus* spp. (Coccinellidae), *Oligota* spp. (Staphylinidae) and maybe *Anthocoris* spp.

(Anthocoroidae) as more important predators. However, these predators contribute very little to mite control because of the frequent use of broad-spectrum pesticides in controlling aphids and mites (Cranham 1985).

Phytoseiid mites are generally absent from hop gardens in Europe, but the occurrence of *Typhlodromus occidentalis* Nesbitt was recorded in the U.S.A. (Cone 1975, Cranham 1985). In Australia, *Amblyseius masiaka* Blommers and Chazeau has been found on hop foliage (Schicha 1980).

2.3.2. Previous Studies on TSSM Infesting Hops

The earliest study of *T. urticae* on hops is, perhaps, the work conducted by Parker (1913) in California in 1911-1912, in which the life history, habits, damage to hop, distribution, predaceous enemies and the control of the red spider, *T. bimaculatus* Harvey (*T. urticae* Koch) was studied.

As the hop is not a high value crop, and as the TSSM was often killed by insecticides or fungicides applied to control other insect pests or fungus diseases, research of *T. urticae* on hops was not fully expanded until the 1960s' when many strains of TSSM in hop fields were found to be resistant to OP's (Lakocy 1964; Luders 1965, a & b; Kolbe 1966, b; Cone 1968; Kolbe and Kaspers 1968; and Cranham 1974).

Much of the work tested the development of resistance of *T. urticae* to certain miticides and evaluated the effect of some miticides in order to find new and more efficient miticides to control *T. urticae* on hops (Parker 1913; Zattler 1948; Kuzanetsova 1962; Kriz and Taimr 1962; Lakocy 1964; Luders 1965, a & b; Kolbe 1966, a & b; Taran 1967; Cone 1968; Cone and Burdajewicz 1972; Cone 1975; Cone and Maitlen 1976; Gesner and Hurkova 1979; Sikura and Taran 1979; Hurkova *et al.* 1983; Korner 1983; Gesner 1984, Hurkova 1984, Troster and Griesel 1983).

The diapause of *T. urticae* in hop gardens was examined by Parker (1913), Jary (1935), Link (1953), Darling (1958), Nuber (1961) and Brandenburg and Kennedy (1981). Cone *et al.* (1986) investigated the reproduction of overwintered *T. urticae* on hops.

Parker (1913) reported that the most numerous predaceous insect which attacked TSSM on hops was a small anthocrod bug (*Triphleps tristicolor* White). Small ladybirds, including two species of *Stethorus* and one of *Pentilia*, were found but only in small numbers. *Stethorus punctillum*, *Orius* sp., *Oligota granaria* and *Tthrips flavus* were found as natural enemies of the hop red spider (*T. telarius (urticae)*) in Czechoslovakia by Blattny and Osvald (1948). The predaceous mite *P. persimilis* was released on hops by Pruszynski and Cone (1972) for control of *T. urticae* and was found established on hops in the U.S.A.. The biology and ecology of another predaceous mite, *Typhlodromus occidentalis* Nesbitt, was investigated also on hops by Pruszynski and Cone (1973). Markwell (1976) reported that *A. longispinosus* was found to occur on hops and attack *T. urticae* in Australia.

Blattny and Osvald (1948) studied the effects of temperature and relative humidity on the development of the hop red spider (*T. telarius (urticae)*). Kac (1961) studied the effect of temperature on the population size of *T. urticae* in hop fields.

Burdajewicy and Cone (1972) investigated the influence of hop leaf density on the growth and spread of TSSM populations, and the vertical dispersion of *T. urticae* on hops was studied by Sites and Cone (1985) throughout the growing season.

Regev and Cone (1975) examined the chemical differences in five hop varieties and related differences to the susceptibility of hops to TSSM.

Peters and Berry (1980 a & b) studied the effect of hop leaf morphology on TSSM and compared 5 hop varieties to investigate their susceptibility to *T. urticae*.

2.4. THE OVERWINTERING OF TSSM

TSSM has various seasonal responses to adapt itself to environmental conditions. The life cycle is characterized by two distinctive colonies: summer and winter colonies. With the approach of winter, females of the summer colony undergo a number of changes in preparation for diapause (Unwin 1971). Diapause is defined as a "genetically determined state of suppressed development, the expression of it may be controlled by environmental factors" (Beck 1980).

Diapause is initiated long before the onset of unfavourable conditions (Beck 1980). Once an organism has entered diapause, it usually has to remain in that state for a certain period, regardless of environmental change (Jeppson *et al.* 1975). Diapause is not terminated until long after the disappearance of those unfavourable conditions (Beck 1980). This phenomenon is very important not only in ensuring the survival of the mite, but also in regulating seasonal phenologies by the synchronization of life cycle and the determination of voltine patterns (Danilevskii 1965).

A detailed knowledge of this phenomenon is of prime importance for the development and application of control measures against this world-wide pest (Veerman 1977). The diapause of TSSM has been studied by many acarologists and entomologists under both laboratory and field conditions and among various host plants. Jeppson *et al.* (1975) stated that diapause appeared to be facultative and controlled by three environmental factors: photoperiod, temperature and nutrition.

The role of photoperiod in the induction of diapause in TSSM was first determined by Bondarenko (1950). Veerman (1977) determined the photoperiodic response curve of TSSM and showed that the photoperiodic reaction was of the long-day type, short days resulting in the incidence of diapause and long days promoting diapause and that the critical daylength (i.e., the photophase duration inducing diapause in 50% of the test population) was about 14 hours at 18 ± 0.5°C. It was considered that photoperiod to be the predominant factor for the regulation of diapause in TSSM.

The effect of various constant temperature on diapause induction was determined by Bondarenko and Kuan (1958) and by Helle (1962). Helle showed that higher temperature tended to suppress the incidence of diapause over the complete range of photoperiods; if the temperature was high enough (25°C in the case of the Dutch strain of TSSM) no diapause was found at any photoperiod.

Nuber (1961) and Parr and Hussey (1966) found that the quality of the food (young and senescing leaves) had certain influence on the diapause of TSSM and that when the photoperiod and temperature were becoming critical, inadequate food supply could have a great effect.

In late summer or early autumn, with the shortening of day-light, decreasing of temperature and unfavourable food supply, young females of the summer colonies stop feeding and laying eggs and leave the host plants by a positive geotactic response (Foott 1964, Unwin 1971, Jeppson *et al.* 1975).

Diapause in TSSM is peculiar in two important aspects: (1) overwintering forms are all adult females that have been fertilized in previous autumn, no males survive; (2) all these females have a bright

orange colour compared with the yellowish-green of the summer forms (Unwin 1971, Veerman 1977, Cone *et al.* 1986).

TSSM hibernates on the ground under leaves, in cracks and crevices, beneath bark scales, or other protected places according to different host plants (Unwin 1971 and Jeppson *et al.* 1975).

Normally, diapause is terminated only by a period of chilling and in this way mites hibernating outdoors are prevented from becoming prematurely active by occasional warm days in winter or early spring (Parr and Hussey 1966). In the spring, with rising temperature and increasing daylength, the winter colonies become active, commence feeding and begin to change colour, then seek out oviposition sites on the new foliage in response to a negative geotactic orientation(Unwin 1971). Under the relatively cool conditions of early spring, the mite population increases slowly and a further two or three months may elapse before significant feeding damage can be observed (Unwin 1971).

In Australia, Fenner (1962) found that, in South Australia orchards, TSSM usually become inactive from April until August with spring activity beginning in September and by November the first spray is usually applied. In Queensland, at a relative low latitude (28° S), the mite persists as the active form on evergreen hosts throughout the year; but on deciduous hosts, mainly apple orchards, winter forms occurred from mid March onwards and there was only a small percentage of the winter form survived (Bengston 1965).

Parker (1913) found that *Tetranychus bimaculatus (urticae* Koch*)* passed the winter upon wild plants in and around hop yards in the U.S.A.. Link (1953) stated that *T. althaeae (urticae* Koch*)* hibernated in hop garden soil to a depth of 10 cm and Jary (1935) found mites frequently

spend the winter in the cracks of hop poles and in the hills. Darling (1958) even found that the mites overwinter among strands of wirework. However Nuber (1961) showed that this mite did not actively migrate into the soil to hibernate for no mites were found in the soil sampled from untilled hop gardens, but he did find some female mite on half-rotten pieces of leaves, seldomly alive, in the soil ploughed in autumn. Nuber believed that these mites were passively carried into the soil by ploughing. Finally he stated that dead shoots and pieces of leaves appeared to be the main winter quarters of the mite in hop gardens. Cranham (1985) stated that the mites survive the winter in the surface layers of the soil and in crevices in hop poles and wirework.

Linke (1953) showed that invasion of young hop plants occurred from the end of April to early May and that the mite appeared on the plants over a period of 6-12 days in air temperatures of 7-10°C.

Nuber (1961) tested the reproduction and longevity of the overwintered females and found that at 20°C and 16: 8 LD, mites lived for 23 days, laying an average of 96 eggs. Cone *et al.* (1986) found that at 18-20°C and 40-50% RH , the overwintered females laid an average of 50.8 eggs over a 20-day test period.

2.5. ASSESSMENT OF TSSM POPULATIONS

An accurate evaluation of mite population density is an important prerequisite to the study of the biology and ecology of any phytophagous mites. However, it is impossible to count all the mites in the field or plot being studied. Thus, the only practicable way of obtaining an evaluation of the mite density is to estimate the relative populations by sampling.

Spider mite populations are usually sampled by periodically counting

the mites on a certain number of leaves. It is generally recognized that mites are not randomly distributed, and this has influenced the development of sampling techniques (Huffaker *et al.* 1970).

Some methods of assessing mite populations were listed by Huffaker *et al.* (1970) and include:

1. counting all mites directly on the leaves;
2. counting only adult females on leaves in the field;
3. washing mites from leaves with a known volume of water and taking an aliquot while the solution is agitated; then the aliquot is transferred to a plate and mites counted;
4. counting mites only on portions of the leaves;
5. leaf-imprint method;
6. use of a mite-brushing machine;
7. counting the mite-free leaves only; and
8. knocking the mites from foliage and branchlets.

Basically, all methods of estimating mite populations above-mentioned may be classified into two categories (i) direct, in which the mites are counted or estimated on leaves, and (ii) indirect, in which the mites are removed from the leaves, then all mites or a fraction in the sample is counted (Morgan *et al.* 1955). Generally, the brushing machine is rated most efficient (Huffaker *et al.* 1970)

The brushing machine, developed by Henderson and McBurnie in 1943, consists of a small electric motor that drives two contra-rotating spiral brushes and a turntable mounted about six inches below them. An adhesive-coated glass disc, five inches in diameter, is placed on the turntable to collect the dislodged mites. The machine is operated simply by inserting and withdrawing a leaf between the whirling brushes. Mites trapped on the disc are counted with the aid of a lower paper counting disc

permanently attached to another glass disc. The mounted counting disc is placed beneath the disc under examination and temporarily glued to it. The counting disc commonly used is divided into 16 sectors of equal area and 12 annuli of equal width. Thus, each sector consists of 12 sections of unequal area. To facilitate counting, every odd-numbered sector is left white and the sectors within the others are made alternatively black and white. It was suspected that the mites were not distributed evenly among the radius of the disc. The percentage error between sectors decreases as the density of mites increases. This machine could remove 100 per cent of the active stages and 98.8 per cent of the eggs of the European red mite and the clover mite from apple foliage. Some results indicated that the brushing procedure was more efficient for estimating populations of phytophagous and predacious mites than microscopic examination of leaves. The procedure is quite useful for estimating the density of mites when they are present in large numbers, and it is so rapid that a large number of samples can be examined in a fairly short time (Morgan *et al.* 1955).

Williams (1979) studied the use of brushing machine in assessing the European red mite on apple leaves and found that the distribution of mites and eggs around the counting disc was non-uniform. By using transformed data, Williams obtained a relationship between mean number of individuals per sector and the number of sectors required to estimate the mean number of mites per sector.

Many sampling and counting methods have been used by various workers. Oatman & McMurtry (1966) and Oatman *et al* (1968) studied populations of *T. urticae* and its predators on strawberries by directly counting infested leaves under a binocular microscope. Mori (1975), in studying *T. urticae* and its predator *Phytoseiulus persimilis,* counted the

active stages of the mites by using a hand lens to examine greenhouse cucumber leaves, while leaf samples of clover from insectary and field bean leaves were examined with a binocular microscope.

A wax immersion method was developed by Trumble *et al.* (1984) in studying *T. urticae* Koch on strawberries. It was found that this method could prolong the time period for counting and therefore increase the number of leaf samples. Furthermore this method eliminated the problems associated with continued development or increased activity caused by handling.

Gupta *et al.* (1975) found that a *T. neocaledonicus* population could be estimated from fifty three leaves plucked at random from the brinjal field and counting the mites from 1 square cm. from anywhere on the lower surface of the leaf.

Baillod *et al.* (1979) used a method based on the percentage of leaves occupied by one or more mites to estimate the risk of damage by *Panonychus ulmi* (Koch) or *Eotetranychus carpini* (Oudm.) on grapevines. It was found that by use of sequential sampling analysis that the sample could be reduced from 100 to 10, 20 or 30 leaves. Cross (1983) found that the mean number of *T. urticae* (all stages) per leaf was approximately the same as the number of leaves with five or more mites present in a 25-leaf sample of strawberries. Hollingsworth and Berry (1982) obtained a similar linear equation to estimate the population of *T. urticae* on peppermint. Bechinski and Stoltz (1985) developed a sequential decision plan for assessing the economic status of *T. urticae* in garden-seed beans. Raworth (1986, b) found that the density of *T. urticae* could be quickly determined in the field using the naked eye, by iteratively observing leaflets for the presence or absence of

the mite. It was found that for a given sample size, the direct counting method always gives greater reliability in comparison with the presence-absence scheme. However, equal reliability could be obtained by increasing the sample size for the latter method. In practice, the presence-absence method is easier and faster to apply than directly counting, especially at high population density (Nachman 1984).

Jeppson (1951) counted adult female mites in the field when studying citrus red mite. Marcano-Brito (1980) found that the number of adult female spider mites was highly correlated to total mite populations on cotton and showed that the total population could be estimated using a linear regression of the total population per leaf versus the number of adult females per leaf. Mollet and Sevacherian (1984) studied *T. cinnabarinus* in cotton by assessing only the number of adult female mites. A well fitted linear regression of the number of adult females per leaf versus the total mite population per leaf of *Panonychus ulmi* (McG.) on lemons was obtained by Jones and Parrella (1984). The same regression for *T. urticae* on cantaloupe was established by Perring *et al.* (1987).

2.6. LIME-SULPHUR AND SUMMER OIL

Lime-Sulphur

Lime sulphur has been used as either a fungicide or an acaricide for over a century. It is an amber-coloured liquid, made by combining sulphur with lime water under conditions of high temperature and pressure, chemically a solution of calcium polysulphides (CaS.Sx) with a small content of calcium thiosulphate. When lime-sulphur is applied on the leaf surface of the plant, following appropriate dilution or on exposure to moist air, the above two

compounds decompose rapidly to release elemental sulphur deposits then produce hydrogen sulphide gas that acts on fungi, some insects and mites. Also, on dilution with water the lime sulphur produces an alkaline reaction and as such is capable of softening the protective wax covering of scale insect and mites, thereby causing death by desication.

The disadvantage of applying lime sulphur is that it is directly toxic to plant tissues, causing scorching of leaves and russeting of fruit, the degree of the damage depends on the concentration employed, the species of plant and the maturity of the foliage sprayed. Some advantages of using it are: (1) no toxicity to the applicator; (2) no residue problem with the crop sprayed; (3) relatively cheap; and (4) relatively specific, so has a minimum influence on the biological complex. It may now be impossible to ascertain the resistance of TSSM to sulphur as mite strains known to have had no exposure to sulphur are no longer available. But the fact is that most of the spider mites in genus *Tetranychus* are not readily controlled by sulphur application. (Jacks and Taylor 1956, Tweedy 1969, Jeppson *et al.* 1975, and Martin and Worthing 1976).

Summer Oil

Summer Oils are refined grades of distillates from petroleum (mineral) oils, which are predominantly hydrocarbon. They are some times called 'white' oils. They have been used to control fungus disease of plants, insects and mites pest as both contact insecticides and ovicides, acting by forming a layer of oil through which oxygen cannot pass, thereby causing

insects and mites and their eggs to suffocate. Performance is influenced by the fineness of oil droplets in the emulsion, by viscosity and by purity. Their main use as acaricides is either on the dormant tree or on foliage.

The phytotoxicity of summer oil is closely related to the degree of refinement. Plant injury can be avoided by using light-medium grade oils. There is no residue problems to the crop or health hazard to the operator. And also, no mites have been able to develop resistance to the 'physical' mode of action of oils.

The effect of Lime-Sulphur and Summer Oil on Mites

Along with the fact that some mites have developed a certain degree of resistance to many organic synthetic insecticides and acaricides and advances in biological control by introducing predatory mites, there arose two main concerns: the effectiveness of sulphur and oil to control mites and their effects on the useful predacious mites.

Generally, lime sulphur kills all active stages of spider mites and thus has rather detrimental effect on predacious mites (McMurtry *et al.* 1970, Veerman 1985). Bognar and Csehi (1959) found that lime sulphur gave good control to *T. telarius (urticae)* on apple trees in Hungary. Nasrulaev (1978) used lime-sulphur as following organophosphorus compound applications to control *Tetranychus* on cotton. Basu & Pramanik (1968) tested nine pesticides against *T. urticae* and proved that lime-sulphur, wettable sulphur and colloidal sulphur all could give at least 75% population reduction 15 days after application. Klett (1965), after experiment both in laboratory and field with hops in Gemany, concluded that there is an acaricidal component in sulphur that is active against *T. telarius (urticae).*

Herue and Putman (1966) found that sulphur was appreciably toxic to phytoseiids. Bartlett (1964 & 1968) showed that lime-sulphur had no toxicity to *Stethorus picipes* and high toxicity to *Amblyseius hibisci* and that the maximum period of residual toxicity retention was up to 4 weeks. Dosse and Musa (1967) found that wettable sulphur had a slightly adverse effect on *Phytoseiulus persimilis,* delaying the increase in population. In 1978, Norizumi and Adachi, after testing 30 pesticides, found that sulphur and colloidal sulphur were highly toxic to *Amblyseius longispinosus* even on the 10th day after treatment and that *A. longispinosus* seemed less susceptible than *P. persimilis.*

In contrast Summer oil kills both eggs and active stages of spider mites and appears to have a less detrimental effect on predatory mites than the sulphurs do. Summer oils have been applied extensively to deciduous and citrus fruit trees as well as to ornamental plants for control of *T.urticae* and some other mites. Legowsiki (1966) found that white oil emulsion was less harmful to predator *P. persimilis* than to *T. telarius (urticae).* Dosse and Musa (1967) showed that white oil emulsion had a slight adverse effect on *P. persimilis,* delaying the increase in population. Bartlett (1968) tested the toxicity of some pesticides to some natural enemies of the spider mites and found that the light-medium graded oil had no toxicity to *S. picioes* and *A. hibisci.* Bishara *et al.* (1980) used the spray of formulations of petroleum fractions to control *T. urticae* on citrus tree and indicated that such sprays offer an outstanding method of control of the pests, especially at the egg stage.

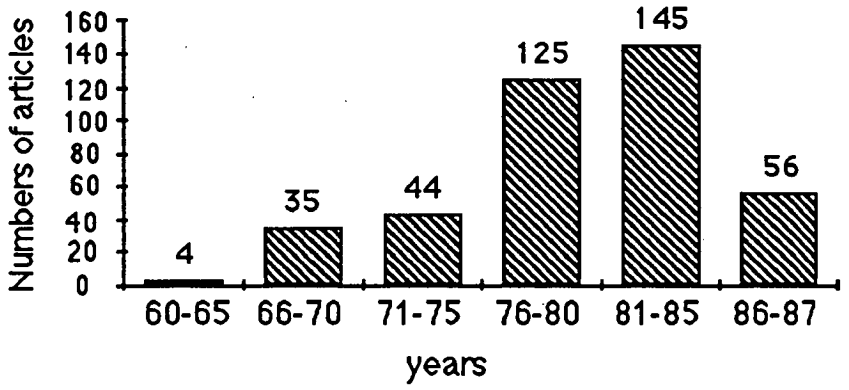
2.7. THE BIOLOGY, ECOLOGY OF PREDATORY MITES *PHYTOSEIULUS PERSIMILIS* AND *AMBLYSEIUS LONGISPINOSUS*

2.7.1. *Phytoseiulus persimilis* (Athias-Henriot)

The phytoseiid mite, *Phytoseiulus persimilis* Athias-Henriot, once synonymized as *P. riegeli* Dosse and *Amblyseius tardi* Combardini in its taxonomic history (Chant 1985, a & b), was originally described in Algeria in 1957, but the material later used for mite control originated from specimens sent from Chile to West Germany. In 1959, Dosse recognized its potential as an agent in controlling spider mites in greenhouses and thereafter it has been sent from Germany to other countries in Europe and to Canada and the United States (Caltagirone 1981).

A survey in noting the number of articles on *P. persimilis* in the Review of Applied Entomology from 1960 to 1987 would reflect the rapid growth of general interest in the predator (Fig. 2.3.).

Fig. 2.3. The number of research articles on *P. persimilis* for the period of 1960 to 1987 (From the *Review of Applied Entomology Ser. A*).



Laing (1968) reported that under a diurnal temperature cycle of 58-83°F (15-28.3°C), the incubation time was 3.1 days, and that larval stages lasted 1.0 days without feeding. The male and female protonymphal stages lasted 1.7 and 1.6 days, respectively, and the deutonymphal stages 1.7 days. Total developmental time was 7.5 days for males and 7.4 days for females. The adult female, after a preovipositional period of 3.0 days, laid an average of 2.4 eggs per day for 22.3 days, giving a total of 53.5 eggs. Upon completion of oviposition, the females lived an average of 7.1 days. The intrinsic rate of increase was measured as 0.219 individuals per female per day and the population multiplied 44.4 times in a generation time of 17.32 days.

As mites are poikilothermic arthropods, environmental temperatures determine the kinetics of biochemical reactions in the mite's physiology (Sabelis 1985, c). Hamamura *et al.* (1976) found that the relationship between temperature and speed of development was linear between 15°C to 30°C for all immature stages. However above 32.5°C, high mortality occurred during development. The developmental period from egg to adult was shorter at 30°C, only 3.5 days, then prolonged gradually with decrease of temperature; and at 15°C, it was approximately 19 days. Stenseth (1979) demonstrated that *P. persimilis* was able to maintain adequate control of *T. urticae* at temperature from 15°C to 27°C, within the RH 60-90% and that high temperature (27°C) and low relative humidity (40% or below) reduced the vitality of *P. persimilis* and favoured development of *T. urticae.*

The prey supply also affects the development of the predator. If the density of juvenile *T. urticae* is equal to 2 per 4 cm^2 leaf surface, *P. persimilis* needs 2.6 days to complete the nymphal stages compared with 2 days at ample prey supply (Eveleigh and Chant 1982). It was found that

female *P. persimilis* expend most of stored food (up to 70%) in egg production and they are capable of depositing an egg mass per day equal to their own body weight (Sabelis 1985, c)!

P. persimilis feeds almost exclusively on tetranychid mites and shows no tendency to reproduce on other types of food. It does not migrate from leaves unless the prey is eliminated. Due to high numerical and functional responses, pest numbers decrease rapidly. Consequently, *P. persimilis* often dies out after all the food is eliminated. When reinfestation of spider mites occurs later in the growing season, *P. persimilis* has to be reintroduced. For these reasons, *P. persimilis* has been mass reared for sale by commercial companies in various countries (Chant 1961 and Overmeer 1985).

Phytoseiids have long been assumed to be blind, actively wandering mites and prey location is a matter of chance. However, this hypothesis has been rejected recently, it has been shown that phytoseiids are able to perceive chemical cues produced by their spider mite prey.

These chemical cues are termed 'kairomones', defined by Sonenshine (1985) as compounds, which are released by individuals of one species and can elicit responses in individuals of another species, and are adaptively favourable to the latter. It has been found that feeding *T. urticae* deposit a volatile compound in the feces, which remains active at the feeding site for brief periods (a few hours) and therefore can be detected by predatory mites such as *P. persimilis.*

The kairomone produced by TSSM can attract the predators *P. persimilis* and *Typhlodromus occidentalis,* but not *Amblyseius potentillae* or *A. finlandicus;* whereas the deposit of the European red mite,

Panonychus ulmi, attracted only the latter two predator species, implying that different prey species emit different

chemical odours that function as kairomones for specific phytoseiid predators (Sonenshine 1985, Sabelis and Dicke 1985).

The utilization of *P. persimilis* to control *T. urticae* on various greenhouse and outdoors crop plants is now worldwide and is particularly successful in greenhouses (see Table 2.2.).

In Australia, Goodwin and Schicha (1979) reported the discovery of *P. persimilis* and its association with TSSM on commercial strawberries in N. S. W.. High numbers of the mite were found subsequently on apple and nectarine trees in a commercial orchard in late summer in Victoria (Ridland *et al.* 1986).

2.7.2. *Amblyseius longispinosus* (Evans)

A. longispinosus (Evans) 1952, once synonymized as *Typhlodromus longispinosus* and *Neoseiulus longispinosus*, is distributed in South America, Southeast Asia, Japan, USSR, New Zealand and Australia. It has been extensively studied mainly in Japan, Taiwan and USSR. Development is strongly affected by temperature, humidity and food supply. Shih and Shieh (1979) studied *A. longispinosus* under 24° C and 70% RH and found that males required an average of 5.06 days and females 5.66 days for the development from egg to adult. While Lo and Ho (1979) showed that under four constant temperature of 20°C, 25°C, 30°C and 35°C with 40-60% RH, the developmental time for males and females was 8.74 and 8.54, 5.93 and 5.69, 4.94 and 5.02, 3.73 and 3.77 days, respectively. Nakagawa (1985) found that the developmental period decreased as humidity increased. As to food supply, Kolodochka (1983) demonstrated that the rate of increase of *A. longispinosus* was higher when the mite fed on eggs of *T. urticae* than on deutonymphs. Saitô and

Mori (1975) found that when *A. longispinosus* was provided with maize pollen in the laboratory, the reproduction rate was lower than when *T. urticae* was provided. It is a common phenomenon in phytoseiid mites that males wait near or upon female deutonymphs which are ready to molt and this suggests that a sex pheromone is involved (Schulten 1985). In *A. longispinosus*, this phenomenon also happens (Shih and Shieh 1979). Furthermore, the females will not lay eggs unless they have mated with males and often they mate more than once (Lo and Ho, 1979).

Fecundity and longevity varies under different levels of temperature (Table 2.3.).

Table 2.3. Life parameters of *A. longispinosus* under different temperatures.

	20°C	25°C	30°C	35°C
eggs/female	47.62	55.63	62.50	47.18
eggs/female/day	1.75	2.33	3.26	3.88
Preoviposition (days)	3.38	2.25	0.86	0.45
oviposition (days)	27.54	24.13	19.21	12.18
postoviposition (days)	9.00	15.75	21.14	13.82
longevity, days	38.38	29.00	22.00	17.82
r_m	0.157	0.229	0.320	0.452
developmental time (egg to egg)	11.92	7.94	5.88	4.22
days for population to double	4.415	3.027	2.166	1.534
mean generation time	20.97	15.00	11.37	7.38

compiled from Lo and Ho (1979).

Prey consumption is affected by temperature, humidity, prey density, stages of prey and the varieties of food supply. Lo and Ho (1979) found that the prey consumption decreased in the following order of temperature

from 25°C, 30°C, 20°C and 35°C. Nakagawa (1985) showed that prey consumption and oviposition by females decreased as humidity decreased

Mori (1967) obtained a domed curve of functional response of *A. longispinosus* preyed on *T. urticae* nymphs and considered that this predatory mite was less predacious than was *P. persimilis*. After comparing the net reproductive rate, developmental time, finite rate of increase, intrinsic rate of natural increase, and prey consumption of *A. longispinosus* with those of *P. persimilis*, *T. occidentalis* and *T. urticae*, Lo and Ho (1979) believed that *A.longispinosus* could effectively control *T. urticae*.

In Japan, *A. longispinosus* was released to control *T. urticae* on red clover in greenhouse either alone or by combination with *P. persimilis*. And it was found that both predators alone effectively suppressed *T. urticae* populations in summer, but the latter predator could not control the pest in autumn (Mori and Saitô 1979). Akimov and Kolodochka (1981) concluded that *A. longispinosus* was a promising predator for use in the biological control of tetranychid mites on greenhouse crops. Whereas Lo and Ho (1984) found that on field strawberries, mass release of *A. longispinosus* gave poor control when the density of *T. urticae* was high, but it could suppress the growth of the prey population within 2 weeks of an initial low prey density of 13/leaf.

In Australia, *A. longispinosus* has been recorded from strawberry, papaw, bean, rose and glasshouse plants. Markwell (1976) studied the life history of this predatory mite and its potential to control TSSM in Queensland.

2.8. ECONOMIC INJURY LEVELS AND ECONOMIC THRESHOLDS

The economic-injury level (EIL) was conceived and defined by Stern *et al.* in 1959 as the lowest population density that will cause enough economic damage to justify the cost of artificial control measures. Southwood and Norton (1973) defined the EIL as the density at which the cost of additional control equals the economic loss prevented by implementing the control tactic. Economic threshold (ET) was defined by Stern *et al.* (1959) as the density at which control measures should be determined to prevent an increasing pest population from reaching the EIL (Onstad 1987).

There has been much inconsistency with respect to these two concepts that some new expressions have been proposed by a number of other authors (Pedigo *et al.* 1986).

The current definition of ET that is used in entomological practice is generally considered as those levels of pest infestation at which the cost of applying the pesticides equals the cost of the damage to the crop if the pesticides had not been applied (Plant 1986)

Onstad (1987) gave general formulas, containing four basic components: pest density, damage, scheduling, and control, for calculating EIL's and ET's.

There are four primary components affecting the EIL: (a) market value, (b) management cost, (c) injury relation to pest density, and (d) host damage per unit of injury (Pedigo *et al.* 1986).

Twine (1984) proposed four distinct phases for the determination of ET's. The first includes the quantification of the host-insect interaction, particularly the effect of insect damage on yield and quality. Secondly, it is the economic impact of the host-insect interaction. The third is the

development of a sampling procedure adequate to define infestation levels. And finally, the threshold must be substantiated.

Adequate economic thresholds have been established for very few of the most important pests of world agriculture, most of which are composed of insects or mites. Unfortunately, many of those that have been determined are only preliminary thresholds (Twine 1984). Of the 19 pests which attack cotton in California, economic thresholds are known for only 5 species (Stern 1973). Jesiotr (1978) found that an increase in mite (*T. urticae)* population density affected rose plant growth as well as the quality and quantity of cut flowers and stated that economic analysis of the results suggested that in plantings of 12 plants/m^2, the economic threshold of injury for the rose was approximately 0.5 mites/leaflet of the compound leaf, equivalent to about 0.06 mites/cm^2. In Swiss apple orchards, Baillod *et al.* (1980) proposed the threshold for populations of *T. urticae* and *Panonychus ulmi* as ranging from 20 to 60 percent of the leaves occupied by the mites. Zalom *et al.* (1984) suggested the provisional control thresholds for *T. urticae, T. pacificus* McG. and *T. turkestani* (Ugar. & Nik.) in California almonds as 44% infestation of leaves in the presence of *Typhlodromus occidentalis* and 22% in its absence. In USSR, Mamedova and Guseinov (1984) determined the economic threshold for *T. urticae* on cotton to be when 7-8% of plants was damaged or when there were 140-200 mites/100 leaves. The author found that the use of the threshold enabled numbers of treatments to be reduced by a factor of 5-10 against *T. urticae,* resulting in considerable savings and increased effectiveness of natural enemies. The economic threshold of *T. urticae* on strawberry was studied by several researchers. Oatman *et al.* (1981 & 1982) found that when economic thresholds of 20-25 mites/leaflet and 90-100 mites/leaflet (50

mites/100 leaves. The author found that the use of the threshold enabled numbers of treatments to be reduced by a factor of 5-10 against *T. urticae,* resulting in considerable savings and increased effectiveness of natural enemies. The economic threshold of *T. urticae* on strawberry was studied by several researchers. Oatman *et al.* (1981 & 1982) found that when economic thresholds of 20-25 mites/leaflet and 90-100 mites/leaflet (50 mites/leaflet would be more acceptable for growers) for winter plantings and summer plantings, respectively, were applied, yields were maximized and the number of sprays minimized. Raworth (1986, a) provided an economic threshold for the strawberry grower based on the number of weeks before harvest, mite sampling precision, differences in environmental conditions, the control measures to be used and the market price.

Economic thresholds depend not only on the effect of pesticide action but also on its timing (Raworth 1986, a). Plant (1986) considered a number of aspects of the economic threshold problem were uncertain for: (a) pest population density is not precisely known, (b) damage caused to the crop by a given pest population is also not known, and (c) mortality due to control action is not under precise control.

CHAPTER THREE

THE OVERWINTERING OF TSSM AND ITS PREDATORS

CHAPTER 3 THE OVERWINTERING OF TSSM AND ITS PREDATORS

3.1. INTRODUCTION

The phenomenon of TSSM overwintering is of importance as hibernating females constitute the potential source for infestation in the next growing season. It has been observed that, in Tasmania, *T. urticae* reappears on hops every year when the plant starts growing in early spring. Therefore, a detailed understanding of every aspect of the overwintering of *T. urticae* and its predators in hops will provide more information for the development of control programmes. In this section, the overwintering sites of, population changes, and the relationship between *T. urticae* and its predator during winter, and subsequent reproduction by overwintered TSSM will be reported from field and laboratory studies.

3.2. MATERIALS AND METHODS

3.2.1. Field Investigation

Field investigations were carried out at Scottsdale (270 km north-east of Hobart city at 41°10' S latitude and 147°31' E longitude, 190 m above sea level) and Huonville (37 km south-west of Hobart city at 43°02' S latitude and 147°04' E longitude , 28 m above sea level) during the winter of 1987 and 1988.

3.2.1.1. The investigation at Scottsdale

The investigation was conducted in a commercial hop field where a predatory mite, *P. persimilis,* after importation from Queensland, had

been released during the previous growing season to control TSSM. The experimental plot consisted of 3 rows of poles wide, running East-West and 38 poles long, North-South, measuring 35 m by 170 m, respectively, or 5950 m^2 in area.

3.2.1.1.1. Population sampling with Black Cloth Traps (B.C.T.)

Ordinary black fabric cloth was cut into pieces, 80 cm in length and 5 cm wide, for use as mite traps in the study of overwintering of TSSM in the hop field. A total of 120 traps were set up on March 12, 1987, two weeks before harvesting.

An individual trap was wound around and fixed on the hop vines of one string at a height of one meter. The 120 traps were equally distributed among five adjacent hop rows, with each trap on every three plants, 24 traps in every row (Illust. 3.1. and Plate 2.). When hops were slashed and harvested, remaining vines and traps were fallen to the ground (Plate 3.).

Traps were collected regularly from April 8, 1987 to September 28, at three-week intervals (with the exception on July 19 and August 19, when the collections were made at two and four week intervals, respectively), with 10 traps collected on every sampling date. Therefore a total of 90 traps were collected throughout the whole overwintering period.

During collection, care was taken to avoid any disturbance to the trap. This was accomplished by cutting the segments of vine, without removing the trap, then each trap-segment was placed in a plastic bag, brought back to the laboratory, and stored at 4°C before inspection. Usually, the time between collection and examining traps was several hours.

The trap was unwound gently, observed with the naked eye first to record live, moving mites, then under a binocular microscope. The

numbers of all mites, prey and predators, dead or alive, and spiders were recorded.

Illustration 3.1. The arrangement of B.CT. in hop field.

---------- HOPS ----------

O X O O X O O X O O X ----------X O O X O O X O O O O O O O O

O O X O O X O O X O O X ----------X O O X O O X O O O O O O O

O O O X O O X O O X O O X ----------X O O X O O X O O O O O O

O O O O X O O X O O X O O X ----------X O O X O O X O O O O O

O O O O O X O O X O O X O O X ----------X O O X O O X O O O O O

X: hops with B. C. T., O: hops without B. C. T..

1 trap/3 plants; 24 traps/row; Σ 120 traps.

3.2.1.1.2. Population sampling with Corrugated Cardboard Traps (C.C.T.)

Corrugated cardboard was cut into individual traps, 60 cm by 15 cm Traps were wound and fixed on hop poles, at a height of 20-30 cm above the ground. A total of 115 traps were set up in the hop field, within the same experimental plot with B.C.T.'s, on March 12, 1987, two weeks before harvesting.

Traps were arranged on 3 rows of poles, with 35 in each row on every adjacent pole, and separated from each other by about 2 m within rows and 7 m between rows (Plates 2. and 4.). Traps were collected on the same date as collecting the B.C.T.'s. The trap was unwrapped carefully and immediately put in a plastic bag. Ten traps were collected each sampling date. The remaining procedures in dealing with the traps were similar to those described in 3.2.1.1.1..

Plate 2. Arrangement of B.C.T.'s and C.C.T.'s before harvesting.

3.2.1.1.3. Examination of litter

Litter around the hop base crown was collected during the winter of 1987. The sample areas were standardized by using a square wooden frame with each side of 34.48 cm (one foot), and height of 3 cm. The frame was held firmly against ground, and all litter inside the frame was transferred into one plastic bag and then treated as one sample lot. Where branches or twigs overlapped the frame, the outside parts were cut and disregarded and only the inside parts included.

Sampling occurred on Apr. 4 (10 lots), May 20 (20 lots), June 10 (20 lots), July 19 (10 lots), Aug. 18 (20 lots), Sep. 8 (20 lots) and Sep. 28 (10 lots) and samples were brought back to the laboratory on the same day. Organisms

were extracted by use of Berlese funnels and trapped in jars containing 75% alcohol and examined under a binocular microscope. Numbers of both TSSM and its predator were recorded.

3.2.1.1.4. Examination of fallen hop leaves and green plants

200 fallen hop leaves and 100 leaves from miscellaneous green plants in the hop field were collected randomly, brought back to laboratory in plastic bags, and examined under a binocular microscope.

3.2.1.2. The investigation at Huonville

Observations and sampling were made in the experimental plot at Huonville in the winter and early spring of 1987 and 1988. The plot was consisted of 3 hop rows wide and 120 hop rows long, set up in a commercial hop field. The predatory mite, *P. persimilis*, was imported from Queensland and released in this plot to control TSSM in the growing season of 1987.

3.2.1.2.1. Examination of litter, fallen hop leaves and green plants

Sampling was conducted three times on June 16, July 7 and July 28 during the winter of 1988. A total of 150 fallen hop leaves (50 each time) and 150 green plants leaves (50 each time) were collected, brought back to the laboratory and checked with a binocular.

Litter in the square frame was separated into two parts, (1) detritus; and (2) twigs and branches. The detritus was directly examined under a binocular. The twig and branch components were first examined directly, then, following cutting longitudinally, their hollow pith cavity.

Plate 3. B.C.T.'s in hop field after harvesting.

Plate 4. C.C.T.'s in hop field after harvesting.

3.2.1.2.2. Examination of thistle leaves

One general observation was made on Aug. 28, 1987. A sample of 160 leaves of California thistle (*Cirsium arvense* (L.) Scop.) was collected from the field on Sep. 19, 1987, placed in plastic bags and transferred, in an ice chest, to the laboratory where the leaves were examined with a binocular microscope. On Sep. 23, 1987, a further 110 leaves of thistle were collected, brought back and examined as described above.

In the winter of 1988, continuous observations and sampling were initiated on Aug. 1, then at one-week intervals, until it became unnecessary. The thistle leaves were put in plastic bags, brought back to laboratory in an ice chest, then examined under a stereomicroscope. The number of mites was recorded.

3.2.2. Laboratory Experiment

Laboratory experiments of the reproduction by overwintered TSSM were conducted in the Department of Agricultural Sciences, University of Tasmania.

Overwintered mites were collected from hop fields at Huonville on September 23, 1987. Those mites which had not commenced laying eggs (identified by finding no eggs on the leaves on which the mites were present) were chosen. Hop leaves, collected from the field, were used to prepare leaf discs. Fifteen leaf discs, 10 mm in diameter, were cut with a cork borer and placed in a round plastic petri dish in two concentric circles on a layer of wet cotton. One overwintered mite was placed on one leaf disc resulting in 15 mites in one petri dish. Six replicates, marked from A to F, were prepared to produce a total of 90 discs. Fresh water was added to the cotton to keep it damp. The lids of the petri dishes were left 20-

30° ajar to prevent excessive humidity. All these dishes were kept in a shade-house which had fluctuating temperatures and humidities very close to that of the open air. Temperature was monitored with a Micromech thermography.

On the 8th day of culturing, all the adult females were transferred onto newly made, fresh leaf discs to prevent the disc becoming overcrowded.

Observations were made at 1-3 days intervals. All the eggs produced by each female were counted and recorded. The larvae were counted as they emerged and removed to leave only the eggs and /or original females on the discs.

3.2.3. Statistical Analyses

The coefficient of dispersion and the coefficient of variation were calculated to examine the dispersion of overwintering TSSM (Southwood 1978, p.27; Zar 1984, pp.410-11). The 2 x 2 test of independence (Sokal and Rohlf 1969, pp. 585-601) was carried out for the data from fields investigations. Simple linear regression method was applied to laboratory data.

3.3. OBSERVATIONS AND RESULTS

3.3.1. Overwintering Sites and the Population Changes of *T. urticae* and its Predators *P. persimilis* and *A. longispinosus*

3.3.1.1. From Scottsdale

The actual records are presented in Appendix 3.1..

T. urticae and a native predatory mite *Amblyseius longispinosus*

(specimen identified by Mrs. M. Williams, Entomologist, Department of Agriculture, New Town, Tasmania) (Schicha 1975 and Collyer 1982) were found overwintering in B.C.T.'s, indicating that these two mites overwintered in the hop field. The number of the two mite species, both alive and dead, are presented in Table 3.1.. Measures of the coefficient of variation (CV) and coefficient of dispersion (CD) (Table 3.2.) indicated that overwintering *T. urticae* were contagiously distributed in sites, i.e., where one occurred there was a high probability of others occurring.

Table 3.1. The number of *T. urticae* and *A. longispinosus* in B.C.T.'s.

Date	*T. urticae*		*A. longispinosus*	
	Alive	Dead	Alive	Dead
8/4/87	31	503	36	4
29/4	7	456	18	13
20/5	2	572	7	9
10/6	0	149	1	0
1/7		2	469	9
2				
19/7	0	447	0	0
19/8	0	28	0	1
8/9		0	5	0
0				
28/9	0	245	0	0
Total n=9	42	2874	71	29

Each figure is the sum of the mites on 10 traps collected on that day. Altogether 90 traps trapped 2916 TSSM, averaging 32.4 mites per trap.

The results of analyzing the relationship between *T. urticae* and *A. longispinosus* is given in Table 3.3.. It was found that the occurrence of predatory mite *A. longispinosus* was associated with the distribution of TSSM during overwintering in hops.

From Table 3.1., it can be seen that the number of live mites, both of prey and predator, decreased as the weather became colder in the winter.

Among the dead TSSM, some had obviously been killed by the predator and the remainder probably killed by cold and rains (Plate 5).

No mites were found among the 90 C.C.T.'s. Only a few (Σ 13) living *A. longispinosus* were found in C.C.T.'s collected on April 8 (1), April 24 (10) and May 20 (2).

The results indicated that *T. urticae* did not overwinter in the C.C.T.'s attached to hop poles, suggesting that the mites did not climb hop poles to seek their overwintering quarters.

Table 3.2. Dispersion characteristics of overwintering TSSM.

Date	No.	m	s	s^2	CV	CD
8/4	534	53.4	100.77	10155	189	190
29/4	463	46.3	68.65	4712	148	102
20/5	574	57.4	63.62	4047	111	71
10/6	149	14.9	17.83	318	120	21
1/7	471	47.1	67.52	4559	143	97
19/7	447	44.7	108.34	11738	242	263
19/8	28	2.8	3.39	12	121	4.3
8/9	5	0.5	1.08	1.2	216	2.4
28/9	245	24.5	75.39	5684	308	232
Total n=9	**2916**	**32.4**	**67.87**	**4606**	**210**	**142**

m=mean; CV= coefficient of variation=s/m;
CD= coefficient of dispersion= s^2/m.

1). CD <1, the population distribution is uniform;

2). CD >1, the population is distributed contigiously, or clusteredly;

3). CD =1, the population has a random distribution.

Table 3.3. The test of independence.

H_0 (null hypothesis): the occurrence of *A. longispinosus* is independent of the occurrence of *T. urticae*;

H_A: the occurrence of *A. longispinosus* is associated with the occurrence of *T. urticae*;

	A. longispinosus		
T. urticae	present	absent	Total
present	29	32	**61**
absent	3	26	**29**
Total	**32**	**58**	**90**

as ad-bc>0, a=28.5, b=32.5, c=3.5, d=25.5.
Quantity 1= 28.5 ln28.5 + 32.5 ln32.5 + 3.5 ln3.5 + 25.5 ln25.5= 295.583
Quantity 2= 61 ln61 + 29 ln29 + 32 ln32 + 58 ln58= 694.825
Quantity 3= 90 ln90= 404.983 G_{adj}= 2 (Q.1- Q. 2+ Q.3)= 11.482
chi-square$_{0.05\ (1)}$=3.841. p<0.005. Therefore reject null hypothesis.
Conclusion: the occurrence of predatory mite *A. longispinosus* is associated with that of the prey *T. urticae*.

The original records for the number of both *T. urticae* and *A. longispinosus* in litter are given in Appendix 3.2. The sum of the number of the mites from 10 lot samples made on each sampling date is presented in Table 3.4..

It was found that TSSM naturally overwintered in the litter at the hop base, and was distributed contagiously (Table 3.5.).

The relationship between the occurrence of *A. longispinosus* to the distribution of *T. urticae* was analysed by applying a 2 by 2 Test of Independence (Table 3.6.) and it was found that when overwintering in the litter, the two species were distributed independently for each other.

There were not any organisms found on either fallen hop leaves or leaves from various green plants in the hop fields during winter.

Plate 5. TSSM killed by predatory mite on B. C. T. .

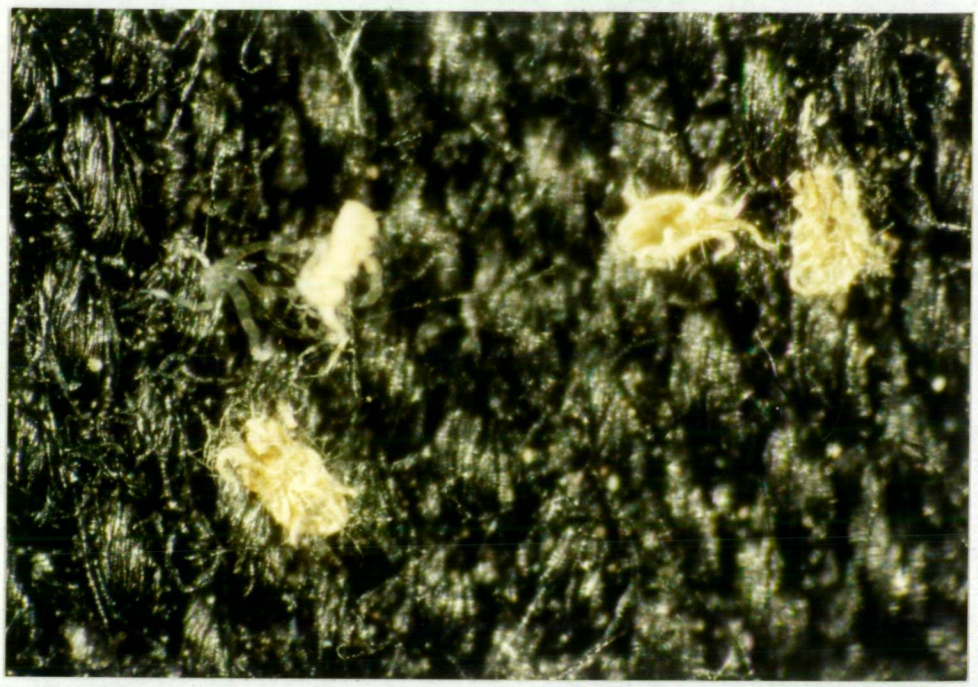


Table 3.4. The number of mites found in litter .

Date	*T. urticae*	*A. longispinosus*
29/4/87	23	16
20/5	101	21
10/6	29	8
19/7	8	0
18/8	11	0
8/9	2	0
28/9	0	0
Total	**174**	**45**

Each figure is the sum of the mites from the litters sampled on that day.

Table 3.5. The variation of TSSM overwintering in litter.

Date	TSSM	Mean	s	s^2	CV	CD
29/4/87	23	2.3	4.32	18.68	188	8
20/5	101	5.05	4.9	24.05	97	5
10/6	29	1.45	3.17	10.05	219	7
19/7	8	0.8	2.2	4.84	275	6
18/8	11	0.55	1.05	1.1	191	2
8/9	2	0.1	0.31	0.095	310	0.95
28/9	0	-	-	-	-	-
Total n=110	174	1.58	3.35	11.24	212	7

Table 3.6. Test of Independence.

H_o: the occurrence of *A. longispinosus* is independent of the distribution of *T. urticae*.

	A. longispinosus		
T. urticae	present	absent	total
present	15	20	**35**
absent	11	64	**75**
Total	**26**	**84**	**110**

G_{adj}= 2 (Q.1-Q.2+Q.3)=1.756

Chi-square $_{0.05\,(1)}$=3.841 Accept H_o, $0.1 < p < 0.5$

3.3.1.2. From Huonville

On March 10, 1988, many orange coloured TSSM were observed moving downwards on the vines.

There were no mites found on either fallen hop leaves or green plants.

No mites were found in detritus or on intact twigs and branches. After stem splitting, various numbers of overwintering mites (ranging from 10-50) were clearly seen present in the middle hollow cavity, the medullary canal. No recording of the number of mites present or absent was made. Obviously, mites aggregate and overwinter inside the small dead hop twigs and branches, for no mites were found singly. Those twigs and branches with mites inside were normally 0.3-0.5 cm. in diameter and several to 10 centimetres long (Plates 6. & 7.). No *A. longispinosus* was found inside any of these cavities.

In late winter, thistles commenced to grow before hops. Overwintered TSSM females were found on the young leaves of newly growing thistles, but not on other plants, on Aug. 28, 1987. On 160 thistle leaves sampled on Sep. 19, 1987, there were 30 *T. urticae* and 24 *A. longispinosus* found. Compared with the observation on Aug. 28, TSSM became more active, but still moved slowly; their orange colour becoming paler and less bright and the dark shoulder spots more conspicuous and darker (Plate 8.). Overwintered *A. longispinosus* were found wandering on these leaves. These mites were of dark colour, with some spots and strips on their dorsum (Plate 9.). On 110 thistle leaves collected on Sep. 23, there were 24 TSSM and 2 *A. longispinosus* present.

In the winter of 1988, thistles started shooting around Aug. 7, but no mites were found until Aug. 18. The results of examining thistle leaves is given in Table 3.7. and Fig. 3.1..

Plate 6. TSSM overwintering inside a hop twig.

Scale: 65 mm. = 5 mm. 2.5 mm.

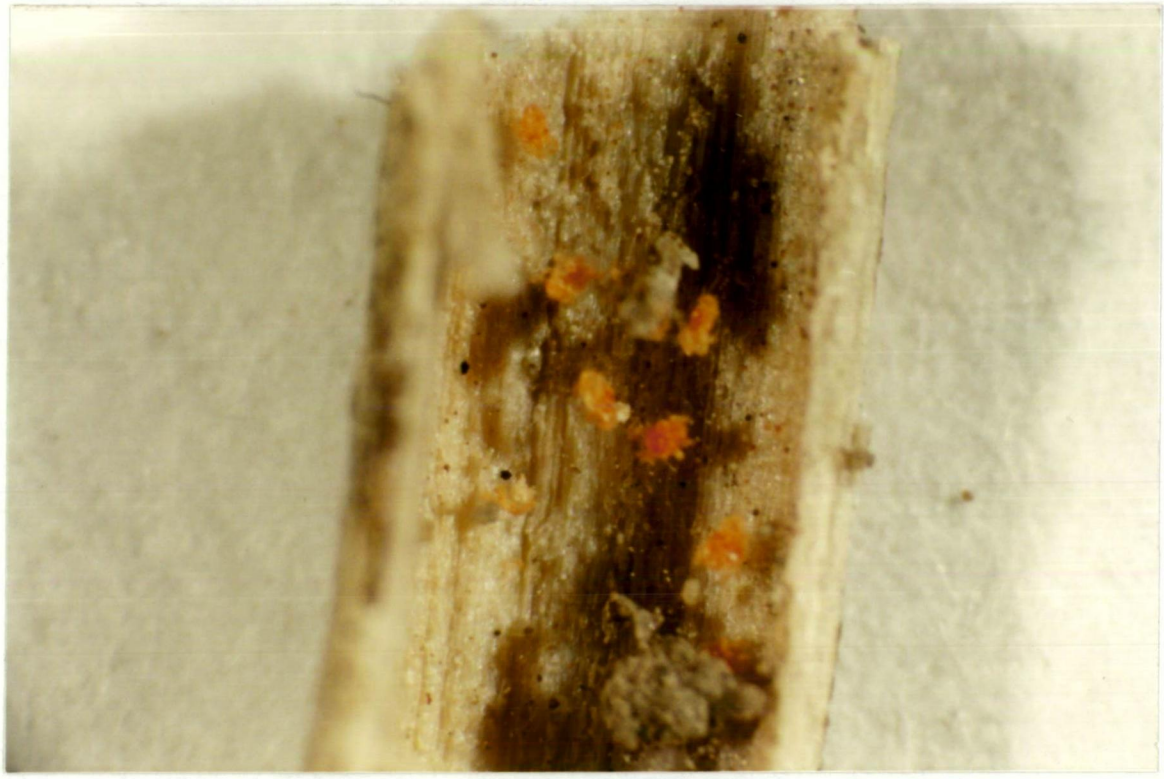


Plate 7 Overwintering TSSM in the cavity of a hop twig.

Scale: 30 mm. = 4mm. 4 mm.

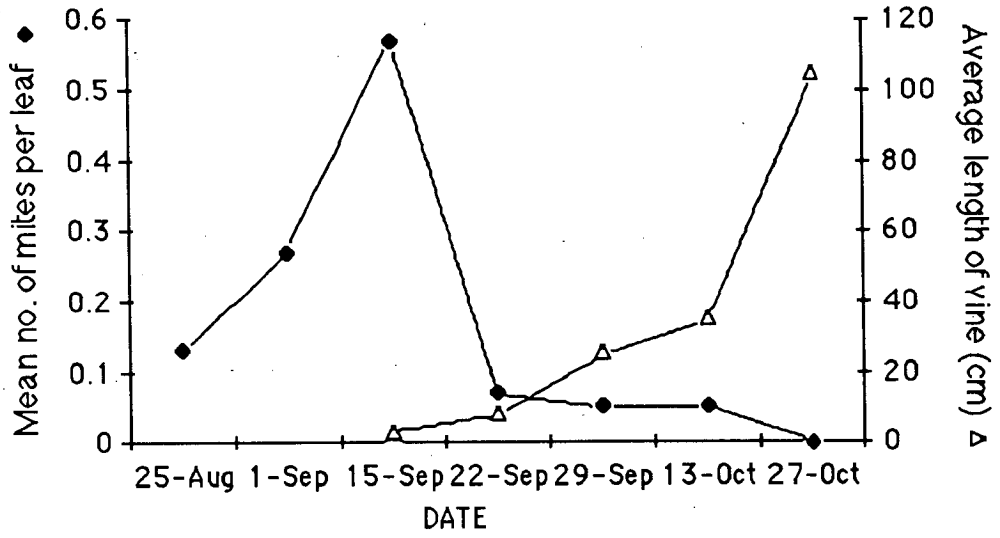
Plate 8. Overwintered TSSM on the lower surface of thistle leaves.

Plate 9. Overwintered *A. longispinosus.*

Table 3.7. *T. urticae* and *A. longispinosus* on the lower surface of thistle leaves.

Date	Leaves	*T. urticae*	*A. longispinosus*	
25/8/88	40	5	0	
1/9	60	16	2	
8/9	110	41	1	
15/9	131	74	4	
22/9	45	3	0	
29/9	80	4	0	
13/10	58	3	1	
27/10	40	0	0	
Total 8	**564**	**146**	**7**	
For TSSM:				
Mean=0.259	s=0.631	s^2= 0.398	CV=244	CD=1.54

Fig. 3.1. Numbers of TSSM on thistle leaves and the growth of hop vines*.



* For more details about hop growth, see 5.2.3..

It can be seen clearly (Fig. 3.1.) that mites terminated diapause in late winter or early spring, at a time just before hop plant started growing. They occurred on thistles, which grew before hops did, before moving over onto hop plants when this host became adequate to feed on.

In all examinations, there were no eggs or webs of TSSM, nor eggs of *A. longispinosus* found on thistle leaves.

The predatory mite *Phytoseiulus persimilis* was not recorded during observing and sampling, strongly suggesting that in Tasmania, this predatory mite cannot establish themselves permanently in hop fields.

3.3.2. Laboratory Experiment

All mites remained on the discs and started feeding immediately. Among 90 mites, 50 provided complete information of their reproduction. The remainder either died by drowning in the water when they crawled out of the leaf discs onto wet cotton after oviposition began, or through food stress by being on rotting leaf discs. Only the statistics from these 50 mites were used in further analysis.

Table 3.8. Daily record of oviposition and eclosion for whole culture.

DATE	A*	B*	C*	D*	E*	F*	G*
25/9/87	1	81.5	34	2.40	5.11		
26/9	2	165.5	50	3.31	10.37		
27/9	3	169	50	3.38	10.59		
28/9	4	155.5	50	3.11	9.74		
29/9	5	148.5	50	2.97	9.31		
30/9	6	73.5	50	1.47	4.60		
1/10	7	77	50	1.54	4.82	2	0.14
2/10	8	133	50	2.66	8.33	0	0.00
3/10	9	132	50	2.64	8.27	1	0.07

(continued)

(continued)

4/10	10	92.3	48	1.92	5.78	12	0.87
5/10	11	87.3	48	1.82	5.47	29	2.10
6/10	12	41.7	38	1.10	2.61	16	1.16
7/10	13	40	37	1.10	2.50	56	4.06
8/10	14	36	33	1.10	2.25	74	5.36
9/10	15	38.9	32	1.22	2.43	66	4.78
10/10	16	26.5	27	0.98	1.66	112	8.12
11/10	17	25.9	26	1.00	1.62	67	4.86
12/10	18	16.9	20	.0.85	1.06	21	1.52
13/10	19	12.5	20	0.63	0.79	60	4.35
14/10	20	15.5	9	1.72	0.97	75	5.43
15/10	21	15	8	1.88	0.94	101	7.32
16/10	22	4.3	4	1.08	0.27	50	3.62
17/10	23	4.3	4	1.08	0.27	21	1.52
18/10	24	2.4	3	0.80	0.19	119	8.62
19/10	25	1	1	1.00	0.06	88	6.38
20/10	26	_	_	_	_	101	7.32
21/10	27	_	_	_	_	36	2.61
22/10	28	_	_	_	_	55	3.99
23/10	29	_	_	_	_	60	4.35
24/10	30	_	_	_	_	44	3.19
25/10	31	_	_	_	_	33	2.39
26/10	32	_	_	_	_	28	2.03
27/10	33	_	_	_	_	8	0.58
28/10	34	_	_	_	_	21	1.52
29/10	35	_	_	_	_	5	0.36
30/10	36	_	_	_	_	9	0.65
31/10	37	_	_	_	_	3	0.22
1/11	38	_	_	_	_	4	0.29
2/11	39	_	_	_	_	2	0.15
3/11	40	_	_	_	_	1	0.07
TOTAL		**1596**			**100**	**1380**	**100**

* A: Days from oviposition; B: Total number of eggs laid on that day;
C: Number of mites laying eggs; D: Average number of eggs laid per female mite;
E: Percentage of total eggs; F: Number of larvae appeared on that day;
G: Percentage of total larvae hatched.

The whole culture was commenced September 23, and survived until November 3, 1987. The original day-to-day records of the egg-laying and larva-hatching for individual mites are given in Appendices 3.3. and 3.4..

Although the winter colouration started to fade away and the dark shoulder spots reappeared and the whole body became more and more greenish, the orange colour did not disappear completely even after all mites had died.

Most of the first or second laid eggs had a dark orange or brown colour and did not hatch but shrivelled. The others were normal pearly white eggs and hatched.

The daily record of egg-laying and larva-hatching for the whole culture is given in Table 3.8.. On the third day of culture, 34 mites started laying eggs. All mites were producing eggs on the 4th day of culture. The egg-laying period lasted 25 days, from September 25 to October 19, 1987, resulting in a total of 1596 eggs laid. The oviposition rate of overwintered *T. urticae* became maximum 2 to 4 days after the mites commenced oviposition (Fig. 3.2.). The second peak of egg-laying appeared 1 day after mites were transferred to new leaf discs, October 2 1987. A regression analysis showed that the number of eggs laid per female per day was partially associated with daily air temperature (Figs. 3.3. & 3.4.).

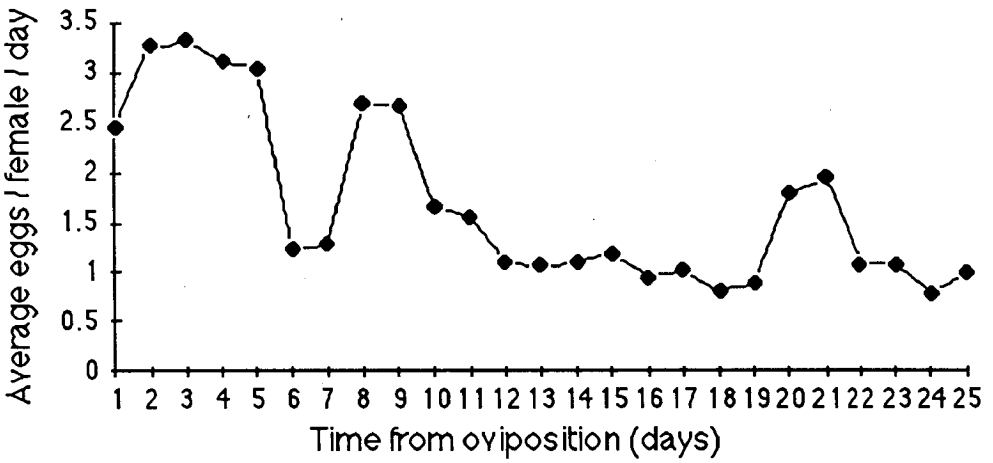
The number of eggs laid by individual mites, the number of larvae hatched from each brood, the duration of egg-laying period for each mite, the larva-hatching period for every brood, the longevity of each mite and the number of days mites lived after they ceased egg-laying are presented in Table 3.9..

Larvae appeared on the 7th day after oviposition began, October 1. Hatching lasted 34 days and had ceased on November 3. A total of 1380

larvae hatched from 1596 eggs, resulting in a hatching rate of 86.47%.

Fig 3.2. Average daily oviposition rate and daily percentage of eggs laid.

a. Oviposition rate.



b. Daily percentage of eggs.

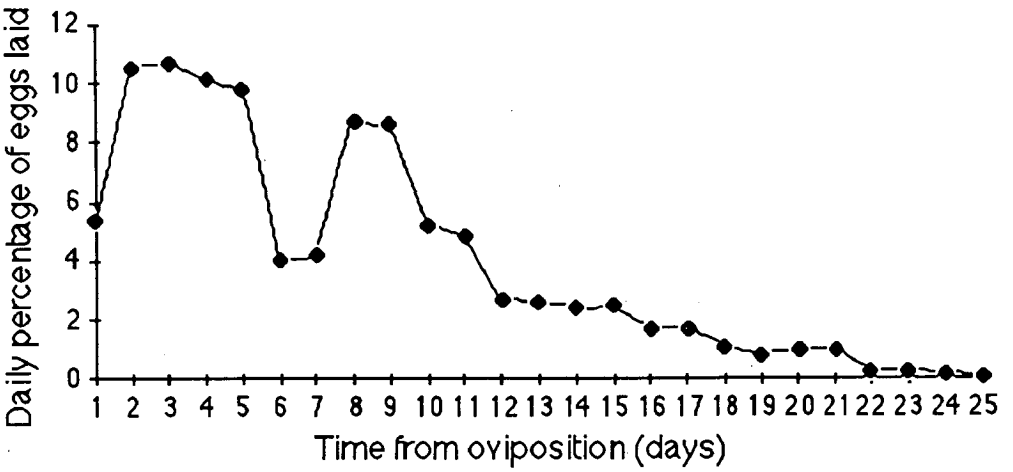


Fig. 3.3. The influence of daily maximum temperature on oviposition.

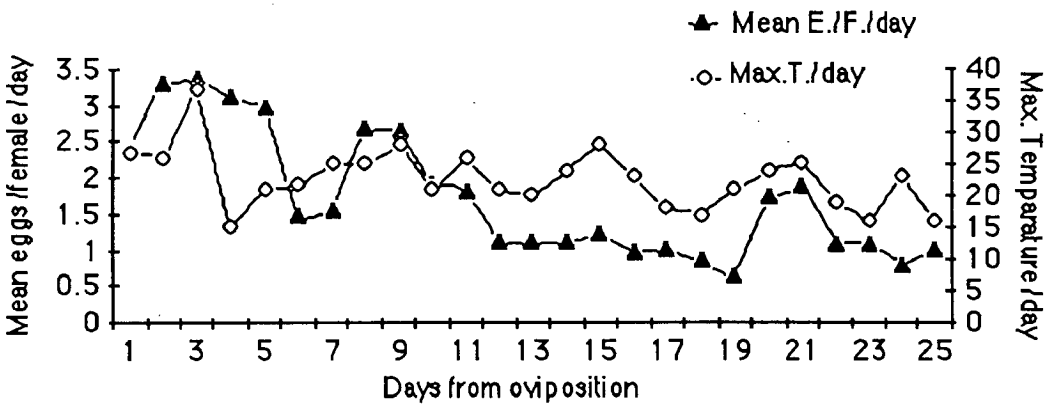


Table 3.9. Oviposition and eclosion of whole culture.

A*	B*	C*	D*	E*	F*	G*
C8	13	10	11	12	3	13
C12	14	10	6	10	1	11
F3	16	16	15	19	4	20
B2	18	11	17	15	10	21
E4	18	16	17	20	5	21
F10	20	8	19	12	11	19
B7	21	12	18	19	5	17
C11	21	12	17	15	8	20
D5	22	15	22	20	2	17
F2	22	11	22	20	13	24
A15	23	19	14	9	7	26
B6	23	18	20	18	2	20
C7	24	13	21	16	2	15
A7	25	9	25	14	2	11
A12	25	11	25	19	6	17
E11	25	20	25	25	2	22
D13	26	14	25	17	2	16
C15	27	11	22	13	3	14
E9	27	14	24	16	3	17
F15	27	17	24	22	4	21
A5	30	11	29	20	9	20
A13	30	15	22	20	2	17
B4	30	11	26	21	3	14

(continued)

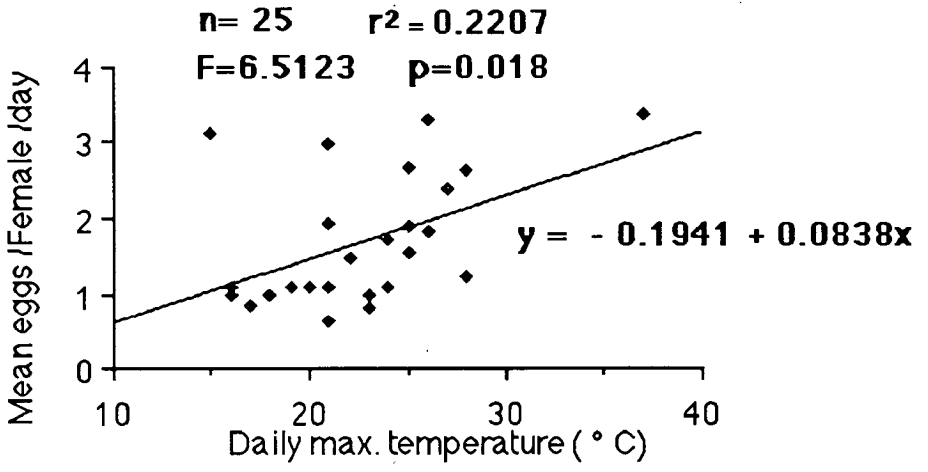
E14	30	18	25	18	5	23
A3	31	12	31	19	7	19
B14	33	16	21	23	7	23
A6	34	11	33	19	1	12
E2	34	19	33	23	1	20
F9	34	21	33	24	3	24
D9	36	18	28	15	2	20
E6	36	20	35	24	6	26
B10	37	12	33	20	8	20
B5	38	18	33	21	1	19
A1	39	18	27	22	3	21
B8	39	17	21	17	3	20
C3	39	15	38	20	2	17
D6	39	13	32	21	4	17
E10	39	20	35	22	3	23
E13	39	24	35	25	1	25
F12	39	17	38	22	4	21
F14	39	17	38	21	4	21
A4	40	11	40	18	8	19
A10	40	18	29	17	1	19
D8	41	19	23	17	2	21
B11	42	23	39	31	1	24
C6	42	18	31	17	1	19
F8	42	17	36	21	2	19
E5	46	24	42	21	3	27
F1	55	24	54	25	5	29
D10	66	19	51	22	8	27
Σ 50	**1596**	**788**	**1380**	**957**	**205**	**988**

Mean Eggs/female =1596/50 =31.92 Mean Egg-laying period =788/50 =15.76
Mean Larvae-hatching/brood =1380/50 =27.6
Mean Larvae-hatching period 957/50 =19.14
Hatching Rate =1380/1596 =27.6/31.92 =86.47%
Averaged days lived by female adult after egg-laying ended 205/50 = 4.1
Averaged longevity of adult females 988/50 = 19.76

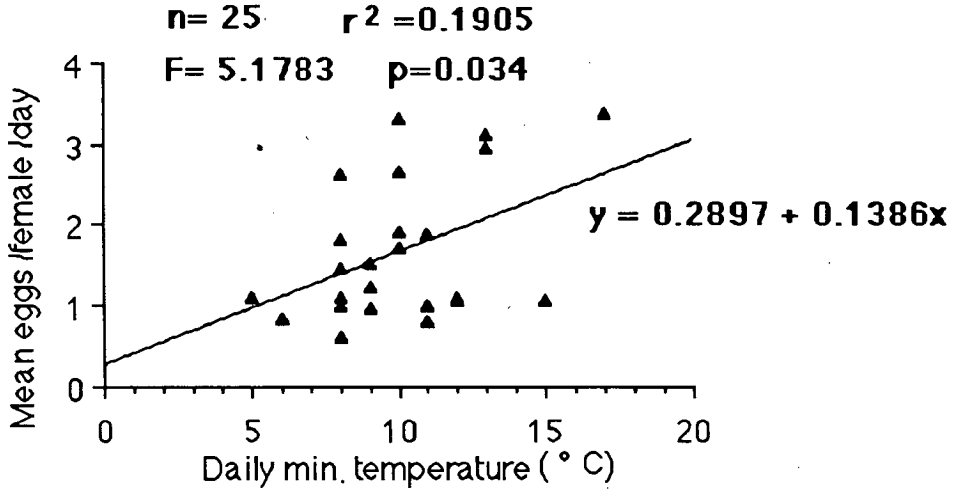
* A: the designation of individual mite; B: number of eggs laid;
C: the duration of oviposition; D: number of larvae hatched from B.
E: the duration of eclosion; F: days lived by mites after oviposition ceased.
G: mite longevity;

Fig. 3.4. The relationship between oviposition and daily temperatures.

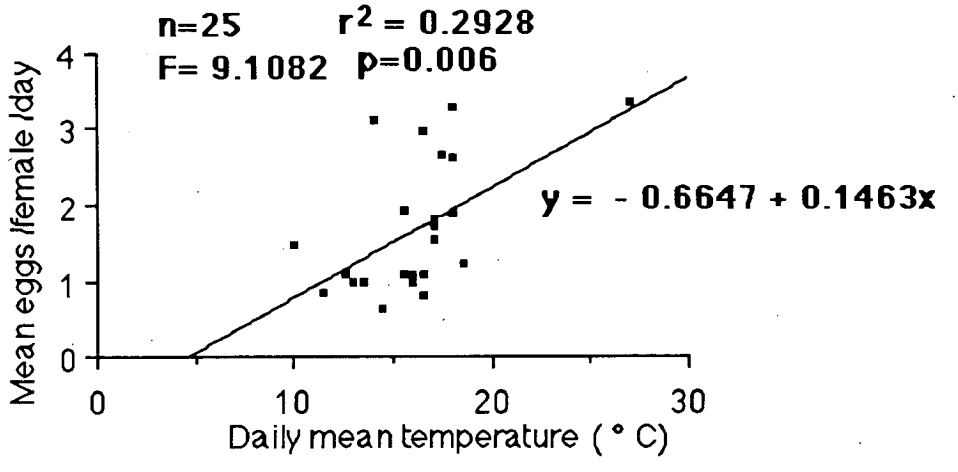
a. for daily maximum T..



b. for daily minimum T..

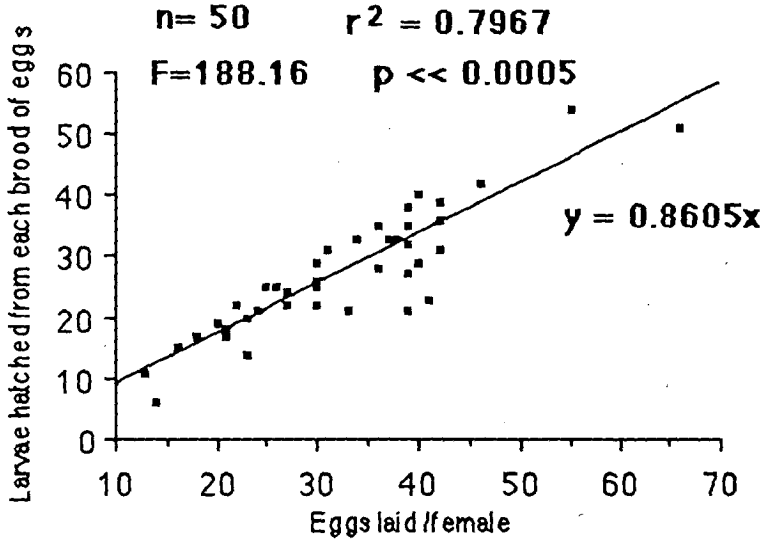


c. for daily mean T..



The average eggs laid per female was 31.92, lasting about 16 days (15.76). The mean larvae hatched was 27.6, which occupied a period of 20 days (19.14). There was a very significant simple linear regression between the number of eggs laid by every female and the number of larvae hatched from each brood of eggs (Fig. 3.5.). The slope of the regression line here represents a hatching rate of 86.05%.

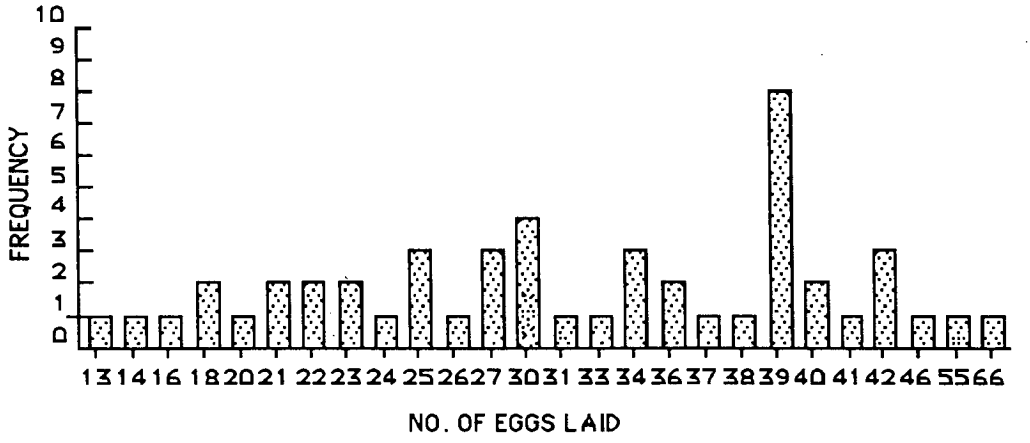
Fig. 3.5. The relationship between number of eggs and number of larvae hatched from them.



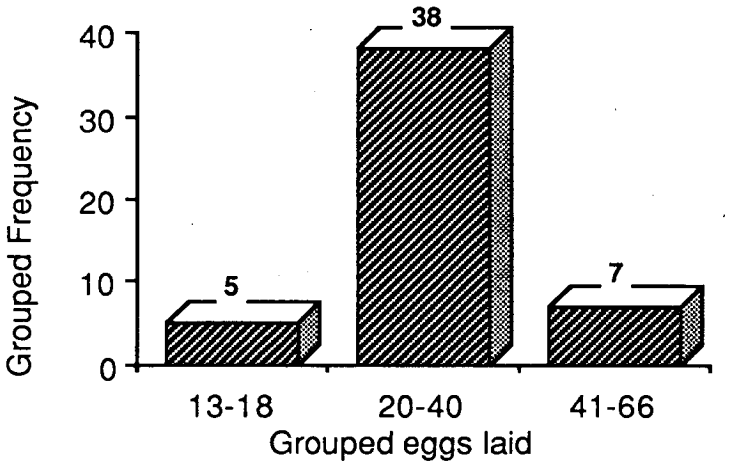
The number of eggs laid by individual mites ranged from 13 to 66. The frequency for numbers of eggs are shown in Fig. 3.6.a. Thirty-eight mites out of 50 laid between 20 to 40 eggs (Fig. 3.6.b.). The duration of oviposition and the eggs laid per female were significantly correlated (Fig. 3.7.a.). There was a significant correlation between the longevity of adult females and the number of eggs they laid (Fig. 3.7. b.).

Fig. 3.6. Frequency for numbers of eggs laid.

a. for individual numbers.



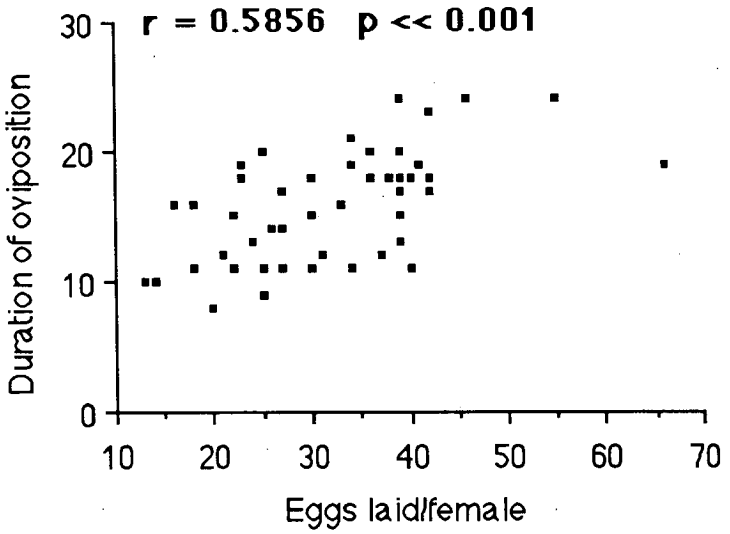
b. for grouped numbers.



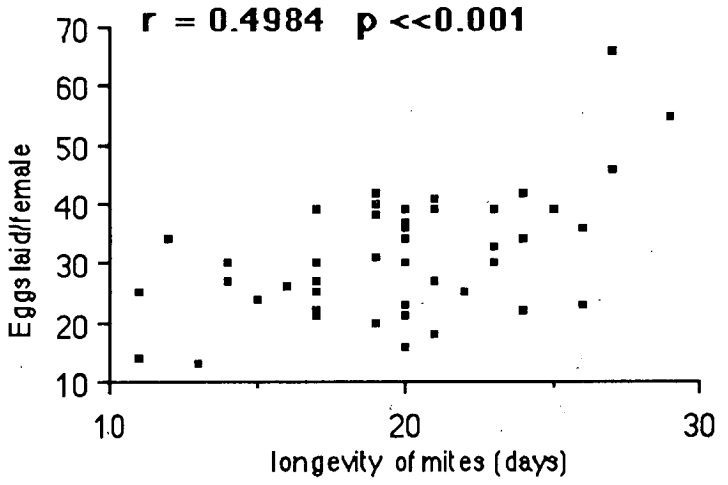
A good correlation was obtained between the number of larvae hatched from each brood of eggs and the duration of these hatching (Fig. 3.8.). It was found that the larvae hatching rate, especially those high peaks, was influenced by daily maximum and mean air temperatures, but not minimum temperatures (Fig. 3.9.).

Fig. 3.7. The relationship between the number of eggs laid, the duration of oviposition and the longevity of mites.

a. between the number of eggs laid and the duration of oviposition.



b. between the number of eggs and the longevity.



It was found that eclosion of mites from eggs was more connected to daily maximum temperature than to daily mean or minimum temperature (Table 3.10. & Fig. 3.10.).

Fig. 3.8. Correlation between the number of larvae and hatching duration.

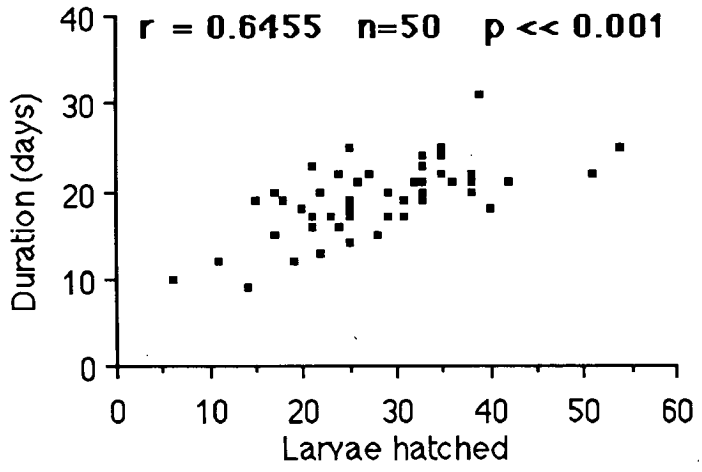
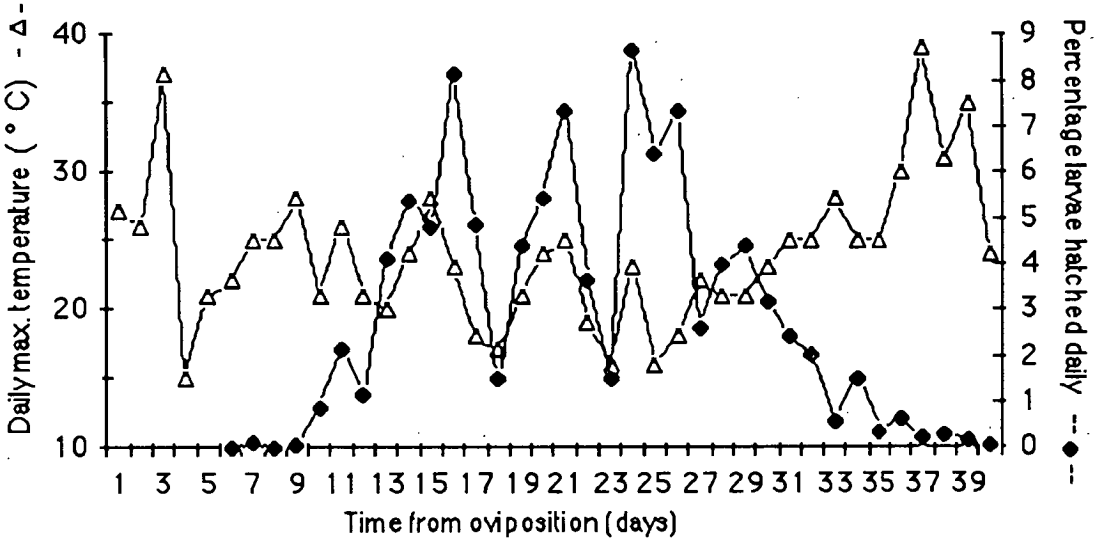


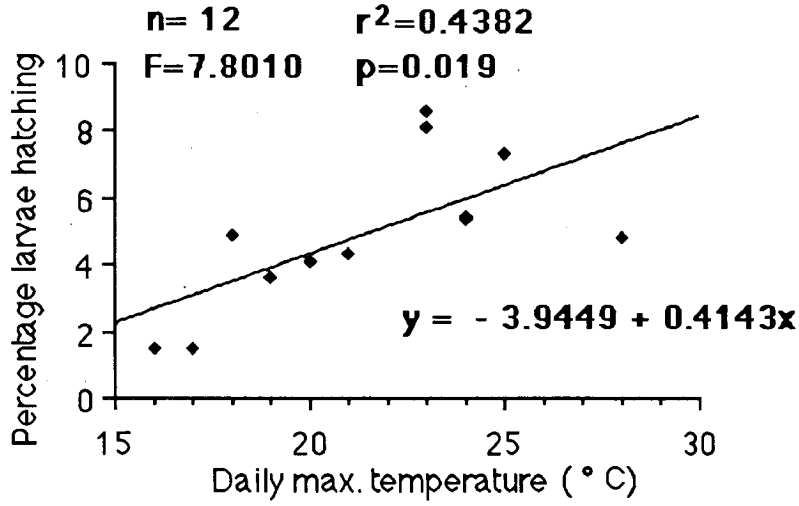
Fig. 3.9. The influence of temperature on eclosion.



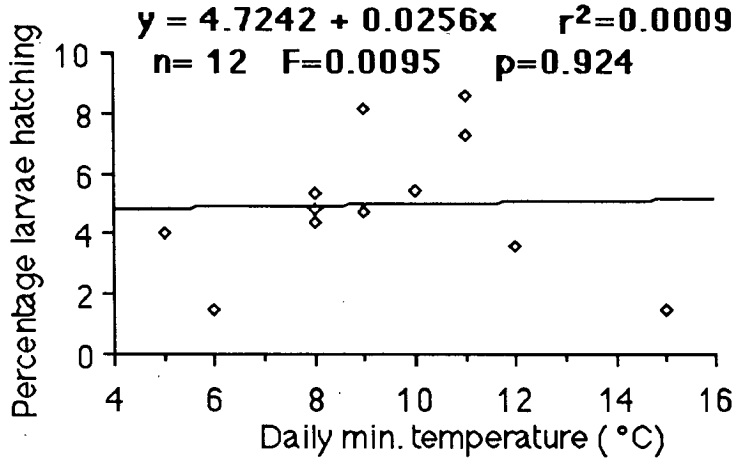
Average oviposition and eclosion parameters for females are presented in Table 3.9 and Fig. 3.11.. There were two peaks in the egg-laying period and by the end of second peak, the 11th day from oviposition, 86.65% of total eggs had already been laid.

Fig. 3.10. The relationship between daily temperature and the percentage of eclosion.

a. for daily maximum temperature.



b. for daily minimum temperature.



c. for daily mean temperature.

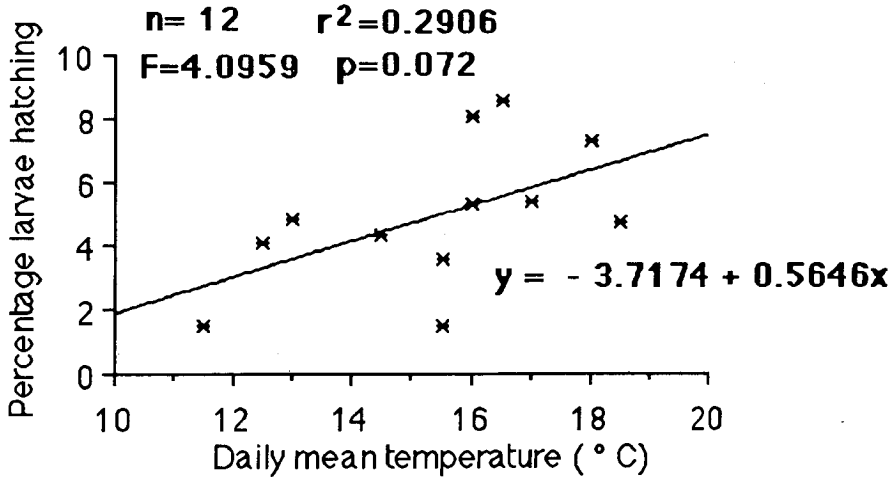


Table 3.10. Simple linear regression for the influence of daily air temperature on hatching.

Hatching period	Percentage	n	r^2	F_t	p
4.06-3.19	87.4	18	0.1138	2.0554	0.138
4.06-4.35	84.21	17	0.1433	2.5086	0.117
4.06-3.99	79.86	16	0.1443	2.3614	0.126
4.06-2.61	75.87	15	0.1470	2.2408	0.135
4.06-7.32	73.26	14	0.1852	2.7281	0.113
4.06-6.38	65.94	13	0.2740	4.1509	0.068
4.06-8.62	59.56	12	0.4382	7.8010	0.019

Table 3.11. Average oviposition and eclosion for TSSM females.

A*	B*	C*	D*	E*	F*	G*	H*
1	5.48	1.75	1.75	_	_	_	_
2	10.75	3.43	5.18	_	_	_	_
3	10.98	3.51	8.69	_	_	_	_
4	10.13	3.23	11.92	_	_	_	_
5	9.70	3.10	15.02	_	_	_	_
6	4.99	1.59	16.61	_	_	_	_
7	5.20	1.66	18.27	17.92	1.26	0.35	0.35
8	8.72	2.78	21.05	20.39	1.12	0.31	0.66
9	8.65	2.77	23.82	22.83	1.19	0.33	0.99
10	6.17	1.97	25.79	24.25	1.99	0.55	1.54
11	5.86	1.87	27.66	25.23	3.22	0.89	2.43
12	2.99	0.95	28.61	25.55	2.28	0.63	3.06
13	2.88	0.92	29.53	25.04	5.18	1.43	4.49
14	2.64	0.84	30.37	24.09	6.48	1.79	6.28
15	2.81	0.90	31.27	23.36	5.90	1.63	7.91
16	2.05	0.65	31.92	21.46	9.24	2.55	10.46
17	_	_	_	19.81	5.98	1.65	12.11
18	_	_	_	19.08	2.64	0.73	12.84

(continued)

19	_	_	_	17.57	5.47	1.51	14.35
20	_	_	_	15.76	6.55	1.81	16.16
21	_	_	_	13.43	8.44	2.33	18.49
22	_	_	_	12.12	4.74	1.31	19.80
23	_	_	_	11.39	2.64	0.73	20.53
24	_	_	_	8.72	9.74	2.67	23.20
25	_	_	_	6.65	7.50	2.07	25.27
26	_	_	_	4.32	8.44	2.33	27.60
TOTAL	26	100	31.92	_	_	100	27.6

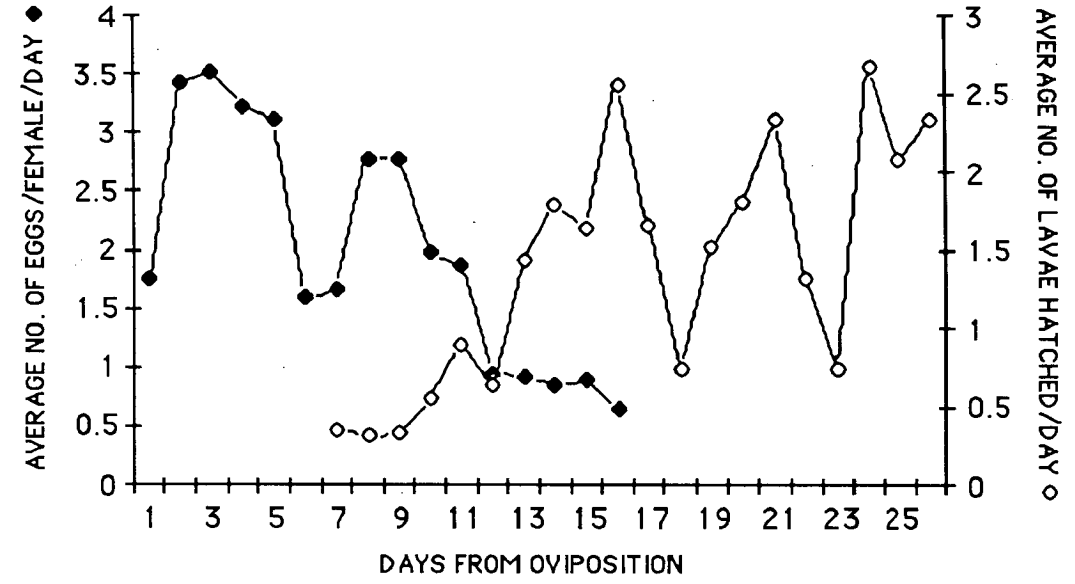
* A: time in days from oviposition; B: percentage of eggs laid; C: number of eggs laid; D: cumulated number of eggs; E: cumulated number of eggs remaining; F: percentage of larvae hatched; G: number of larvae hatched; H: cumulated number of larvae.

3.4. DISCUSSION

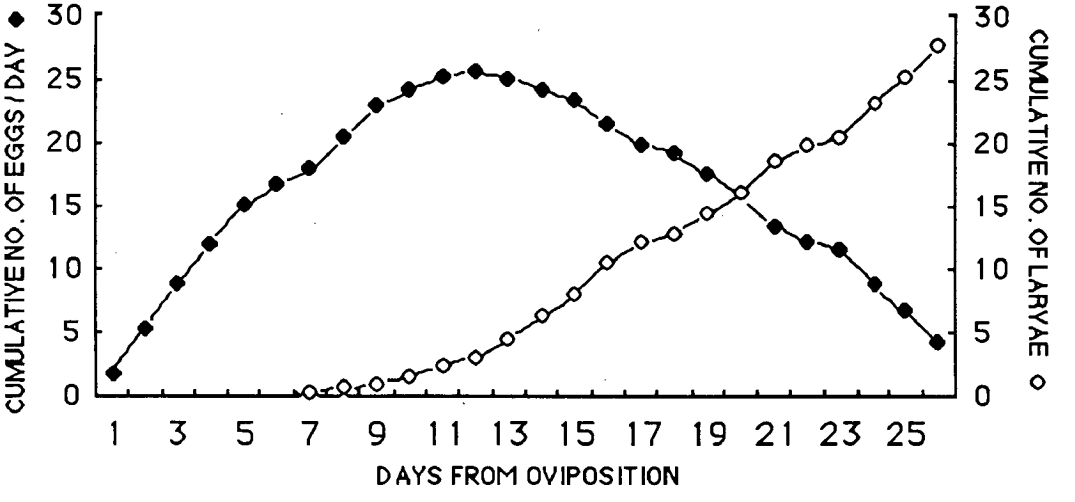
As indicated by Veerman (1977), a complete knowledge of diapause in *T. urticae* is of prime importance for the development and application of control measures against this most destructive pest. The same is true for its natural predators. The important aspects of diapause in *T. urticae* and its natural predators would include (1) a knowledge of exact habitats, (2) population dynamics of diapausing mites, (3) the time of initiation and termination of diapause, (4) behaviour following termination of diapause, and (5) the reproduction of the overwintered females.

Fig. 3.11. Average and cumulative oviposition and eclosion per female mite.

a. for average numbers.



b. for cumulative numbers.



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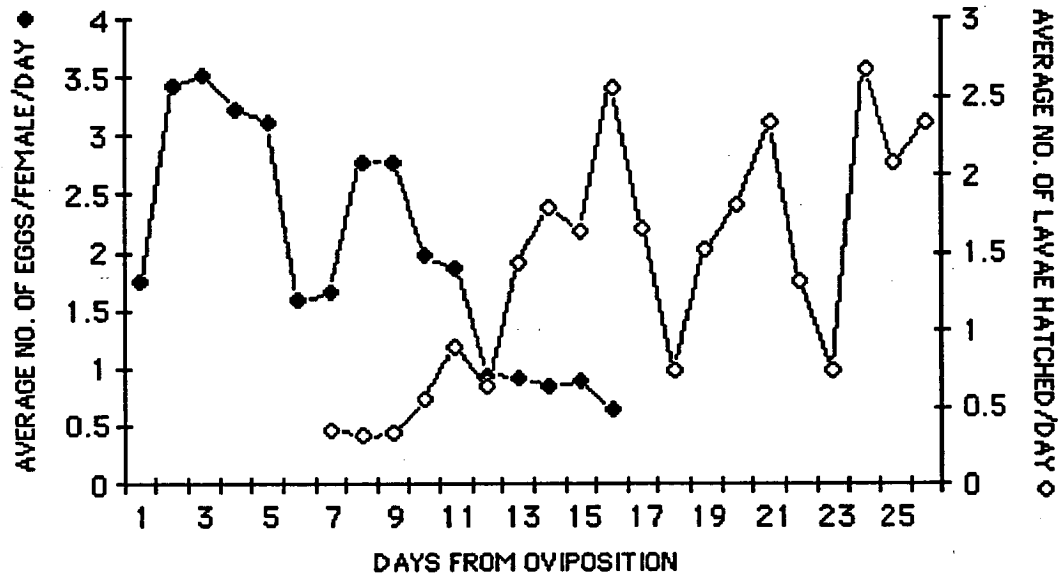
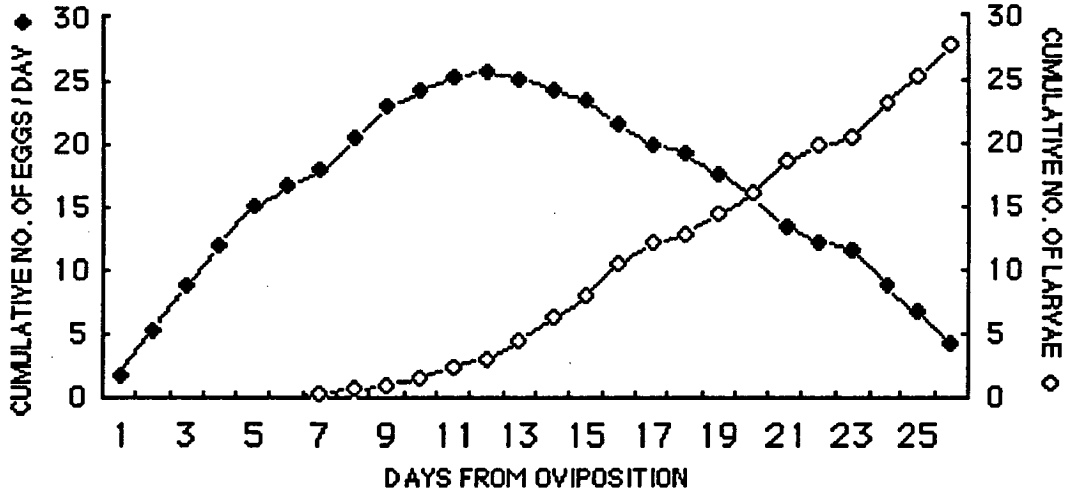
a. for average numbers.



b. for cumulative numbers.



3.4.1. Overwintering Refuges

It is well known that *T. urticae* overwinters in well protected sites, such as hidden places in greenhouses, cracks and crevices under bark, dried leaves and clods of earth in outside situations (Parr & Hussey 1966, Veerman 1985).

Cranham (1985) stated that *T. urticae* survived the winter in the surface layers of the soil and in crevices of hop poles and wirework. According to the results, this mite did not spend winters in hop poles in Tasmania, for there were no TSSM found in C.C.T. attached tightly to the hop pole. Nor does the mite overwinter in the surface layer of soil as there was no mite found directly from the detritus and the surface of hop fields in Tasmania was so firm that it is unlikely that the mite could penetrate this surface. The finding of large numbers of diapausing mites present in the B.C.T. would suggest that before harvest, in early- or mid-March, the mites moved downwards along the vines to find their hibernating sites. This is in agreement with the findings of Sites and Cone (1985), that when the downward migrating deutogynes, which developed in late August and early September, reach the bottom of the hop plants, they leave the vines to find overwintering sites, rather than move onto leaves. That no live mites were present in the B.C.T. after July 1 probably indicated that these artificial traps were not cold-proof enough for mites to survive the freezing winter. However, considering the number of mites these traps caught (32.4 mites/trap), it may be of some value in artificially increasing the mortality of the diapausing adult females.

Nuber (1961) found that pieces of hop leaves and dead lateral shoots provided overwintering sites for TSSM. Parker (1913) found that the mites passed the winter upon wild plants in and around the hop yards, but did

not give the exact hibernating site. The results from this investigation showed that fallen hop leaves or green grasses were not inhabited by diapausing mites, but only the shoot stumps were used as hibernating sites. Nuber (1961) reported that the mite did not go into the medullary canal of the main stem but only the lateral shoots which were still alive in winter with only the tips dead and still attached to rootstocks. However, in Tasmania, those shoots, which were used as overwintering quarters by TSSM, were all dead and scattered above ground around the rootstocks without direct attachment to the rootstocks. Furthermore, the medullary canals in those dead shoots were quite large cavities which provided enough space for the mites to form colonies. In fact, this finding is rather disappointing from the point of view of pest control management, for no practicable control measures can be applied once the mites have got into the hollow cavities of the dead shoots except physical destruction.

Since *A. longispinosus* is a native species, it must overwinter in hop fields every year. The results showed that when overwintering in hop fields, this mite was associated with its prey in B.C.T., but not in litter. This predatory mite spends winter in the litter around rootstocks, and this is in agreement with the observation made by Takahasho and Mori (1979) in Japan that the hibernation of this species usually occurred in ground litter near the summer habitat.

Although *Phytoseilius persimilis* was released in previous growing seasons, no mites were found during either winter, or recovered from sampling in the following seasons.

Hussey and Scopes (1977) stated that *P. persimilis* does not hibernate, and must be reintroduced into glasshouses every season, and this is

generally accepted. But McMurtry *et al.* (1978) found that after releasing this mite in commercial strawberry fields for many years (6 to 7), *P. persimilis* became established permanently and played a very important role in controlling TSSM on strawberry in California. What is more interesting is that this mite was discovered as a native predatory mite in Australia. Goodwin and Schicha (1974) reported that *P. persimilis* was found on strawberries near Sydney in December. Then Ridland *et al.* (1986) reported its occurrence in orchards of apple and nectarine trees at Werribee, Victoria between February and April, and no mites found until late summer in the following season. A comparison of the mean daily max. and min. temperatures in all months for Sydney (N.S.W.), Werribee (Victoria), Scottsdale and Huonville (Tasmania) (Table 3.12.) would suggest that temperature, especially the mean daily min. temperature during winter, i.e., June , July and August, has a checking effect on the distribution of *P. persimilis*, and that the successful permanent establishment must depend on the adaptation of *P. persimilis* to the cold winter in Tasmania.

3.4.2. Population Changes in Diapausing

So far, very little work has been done on the population dynamics of overwintering mites, either on TSSM or on *A. longispinosus*.

It has long been known that a substantial mortality occurs in the overwintering population of *T. urticae* and that only a small percentage of diapausing mites successfully survive the winter. Consequently spring populations are normally low (Bengston 1965). It is very obvious from the results of examining litter and B.C.T. that there were many more dead than live mites during the winter and that the number of live mites decreased as the winter became colder.

Uchida (1980), in Japan, found that there was a high correlation between the number of summer females on leaves in late September and the abundance of overwintering females. Also, diapausing mites exist as a potential source of new infestation in the next season. Therefore, it is possible that the number of mites surviving from winter to infest newly growing crops can be predicted from the number of mites present in the late summer previously, with a certain degree of accuracy.

Table 3.12. The Comparison of latitudes and temperature in regions where *P. persimilis* was found.

Latitude												
Sydney region (N.S.W.)												33 Deg. 52 Min. S
Werribee (Vic.)												37 Deg. 54 Min. S
Scottsdale (Tas.)												41 Deg. 11 Min. S
Geeveston (Tas.)												43 Deg. 9 Min. S
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean Daily Maximum Temperature (°C)												
Sydney region	25.7	25.8	25.1	23.3	20.1	17.8	17.1	18.0	20.1	22.1	23.8	25.0
Werribee	25.6	26.0	23.6	20.6	16.3	13.7	13.4	14.5	16.3	19.5	21.3	23.8
Scottsdale	22.5	23.6	21.0	18.1	14.7	12.0	11.9	12.2	13.9	16.0	17.	20.1
Geeveston	22.8	23.3	19.4	18.2	14.9	11.6	12.2	13.2	15.5	17.1	18.4	19.7
Mean Daily Minimum Temperature (°C)												
Sydney region	18.8	19.0	17.1	5.0	11.5	9.6	8.3	9.3	11.2	13.9	15.7	17.5
Werribee	13.5	14.6	12.2	9.9	7.3	4.7	4.3	5.0	6.1	7.8	9.6	11.8
Scottsdale 10.6	12.0	8.7	7.7	4.9	2.1	2.1	3.3	4.6	5.2	7.3	8.9	
Geeveston	9.2	10.4	7.5	7.3	6.1	1.3	1.0	1.9	5.2	5.1	6.8	8.7

(information from Bureau of Meteorology, 1975)

The fact that the number of live *A. longispinosus* from the B. C. T. and litter decreased as the winter became colder would indicate that mortality occurred in the overwintering population. That this mite was still killing TSSM in late autumn and early winter is of importance in increasing the mortality of TSSM and may indicate the importance of food in the preparation for its diapause.

3.4.3. The Time of Initiation and Termination of Diapause

Diapause of *T. urticae* is generally believed to be initiated by shortening daylength, which is of predominance, decreasing temperature and unfavourable food supply and terminated by increasing daylength, increasing temperature and more favourable food resource after an indispensable chilly period (Jeppson *et al.* 1975, Veerman 1985). Furthermore, Jeppson *et al.* (1975) indicated that, for this mite, diapause termination depends chiefly on rising temperature. Fenner (1962) found that in Adelaide Hills orchards, the mites remained inactive usually from April to August and began to be active in September. Bengston (1965) reported that in Queensland commercial apple orchards, winter forms occurred mainly from mid-March onward, and into the winter months, June-August. Okuhara and Hamamura (1979) found that mites from a high latitude entered diapause earlier than those from low latitude and that the time of the termination of diapause also differed. From this investigation, it is believed that summer TSSM form commenced to change into the winter form around March 10 in 1988 at the Huonville hop field. Diapause terminated in early August in both 1987 and 1988. Mites enter diapause before harvesting which usually begins around late-March.

Hamamura (1982) reported that in Japan, the females of *A. longispinosus* entered diapause in November and moved to their hibernation sites in December. It seemed that the onset and termination of diapause in this mite synchronized with its prey, but it still actively sought and killed its prey in the early stage of diapausing.

3.4.4. The Behaviour of Overwintered Mites

Jeppson *et al.* (1975) stated that overwintered females of *T. urticae* usually commence to feed on weeds in early spring, and that they spin webs and lay eggs on this first feeding site. Although the mite was found, in this experiment, to occur and feed on thistles after completing diapause, there were no eggs nor webs observed on thistle leaves. Nevertheless, the finding that the mites occurred on thistles first then moved onto hops is of practical importance, as it provides a advantageous opportunity to apply control measures to eliminate the mites before they move onto hops. (see later 5.3.5.1.)

It was found that *A. longispinosus* actively fed on TSSM on thistles after reviving from diapause. Then they moved onto hops to follow their prey. However it appeared that they did not consume large numbers of prey as they normally do in the summer, for there were few TSSM killed by this predator when it was present on thistles. This behaviour is of ecological importance in terms of integrated mite management.

3.4.5. The Reproduction of Overwintered TSSM Females

It is well known that TSSM females are fertilized in autumn to produce both sexes after emerging from diapause. Only two reports, Nuber (1961) and Cone *et al.* (1986), on the reproduction of overwintered females in hops have been found so far. However, these two investigations were all carried out in the laboratories under controlled conditions. Considering the fluctuation of temperature in late winter and early spring, an investigation of field conditions would be ideal.

Nuber (1961) stated that the number of eggs laid by overwintered females and the length of time these females live are factors that have a great bearing on eventual population density. Under a stable temperature of 20°C, Nuber

found that mites lived for 23 days and laid an average of 96 eggs. Cone *et al.* (1986) reported that the average number of eggs laid per female was 50.8, over a 20-day test period at 18-20°C, 40-50% RH, but did not give the longevity of these mites. In the present test, the average number of eggs laid per female is 31.92 in 15.76 days, lower than the numbers quoted above, mites lived for only 19.76 days, also shorter. Nuber (1961) pointed out that winter females, which had survived cold temperatures, had a disposition to transform as quickly as possible into egg-laying summer females. From the results of this investigation, it is further indicated that overwintered females produce all their eggs as fast as possible. This can be enhanced by the fact that by the 11th day of oviposition, 86.65% of total eggs was already laid and that after they had laid all their eggs, the females only lived 4.1 days before they died.

Nuber (1961) found that temperature and light had considerable influence on the transformation of winter forms to egg-laying females. It is shown in the present study that temperature had a significant influence on daily egg-laying and daily eclosion of larvae. Therefore, the temperature in early spring is assumed to be the main factor in governing the build-up of subsequent mite populations in hop fields.

It is also demonstrated that the quality of food supply affected the daily egg-laying.

CHAPTER FOUR

ASSESSING TSSM POPULATIONS IN HOPS

CHAPTER 4 ASSESSING TSSM POPULATIONS IN HOPS

4.1. INTRODUCTION

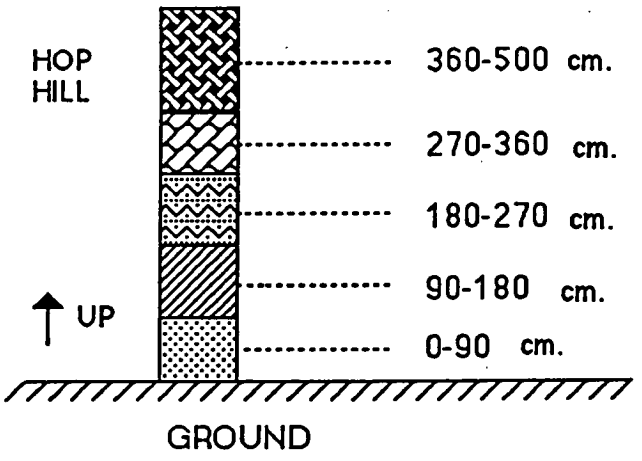
Accurate estimation of mite populations is essential for pest management programmes. However, it is generally considered that sampling mites is both tedious and time consuming work, because of the small size (The largest adult females can just be seen with naked eye), and the large number of mites on leaves. When a mite brushing machine is employed to remove mites from leaves onto counting discs, the counting is usually made on the basis of sectors. According to Williams (1979), when the mean number of individual mites per sector is 256 or more, it is sufficient to count only one sector on the disc. However, in studying TSSM in hops it was found that as each sector consists of white sections as well black ones, it required much more effort and time to count mites on white sections than on black because of the reflection of light from the illuminating microscope lamp, the many tiny yellowish glands (These saucer-shaped glands are present on the undersides of hop leaves) dislodged together with mites from hop leaves and also the paler colouration of some mite stages, particularly the tiny opal and translucent eggs! Therefore, an easier and simpler way, in which mites can be counted only on black sections, was required. This chapter will investigate the possibility of estimating mite densities in modified and simpler ways by: i) counting only black sections on the conventional brushing-machine counting disc; ii) estimating the density of mites of all stages by counting only the number of adult female mites; iii) estimating the whole mite population by counting adult female mites in the field with naked eye; and iv) estimating mite density on individual leaves by counting only part of the leaf.

4.2. MATERIALS AND METHODS

The experimental plot was established in the middle of one hop field, four ha. in size, at Huonville in early September, 1987 and its dimentions were three hop rows wide (running southeast), and 120 hop rows long (running southwest), and was approximately 0.12 ha. in size.

Hop plants were longitudally divided into five strata with height intervals of: 0-90 cm, 90-180 cm, 180-270 cm, 270-360 cm and 360-top (normally 500 cm) (Fig. 4.1.).

Fig. 4. 1. The five height intervals of a hop plant.



4.2.1. Development of a Modified Counting Method

4.2.1.1. Designing count tracks

A Henderson-McBurnie mite brushing machine was employed to remove mites from hop foliage. The counting disc, used to collect dislodged mites, is divided into 16 sectors of equal area and by 12 annuli of equal width. The annuli divide each sector into 12 sections of unequal area. Among 16 sectors, every other sector is completely white, and the adjacent sectors are divided into black and white sections. These latter sectors are marked from 1 to 8 in a counter-clockwise direction (Fig. 4.2.). The 12 annuli were designated by Roman figures as I, II, III, IV, V, VI, VII, VIII, IX, X, XI and XII, beginning from the outermost peripheral annulus running inward to the twelfth annulus. Thus, sections of the blackened sectors can be designated by the number of the sector and the number of the annulus, for example, section 2-II is white, the second section in sector 2, and section 8-VII the seventh section, black in sector 8 (Fig. 4.3.).

There were 4 sectors which had their section I black and section II white, then alternately black and white; while in the other 4, their section I was white and section II black, and so on. Altogether, there were 44 black sections on one disc.

Counting was commenced in the outermost black section of a sector and then, in a counter-clockwise spiral, to the next inner black section of each alternate sector until the eleventh black section in the corresponding sector (Fig. 4.4.). This manner of counting was subsequently referred to as the " modified counting method".

Fig. 4.2. Counting disc for Henderson-McBurnie mite brushing machine. Black and white sectors are marked from 1 to 8, four of which have 6 black sections, while the other four have 5, yielding a total of 44 black sections for each disc (from Morgan *et al.* 1955).

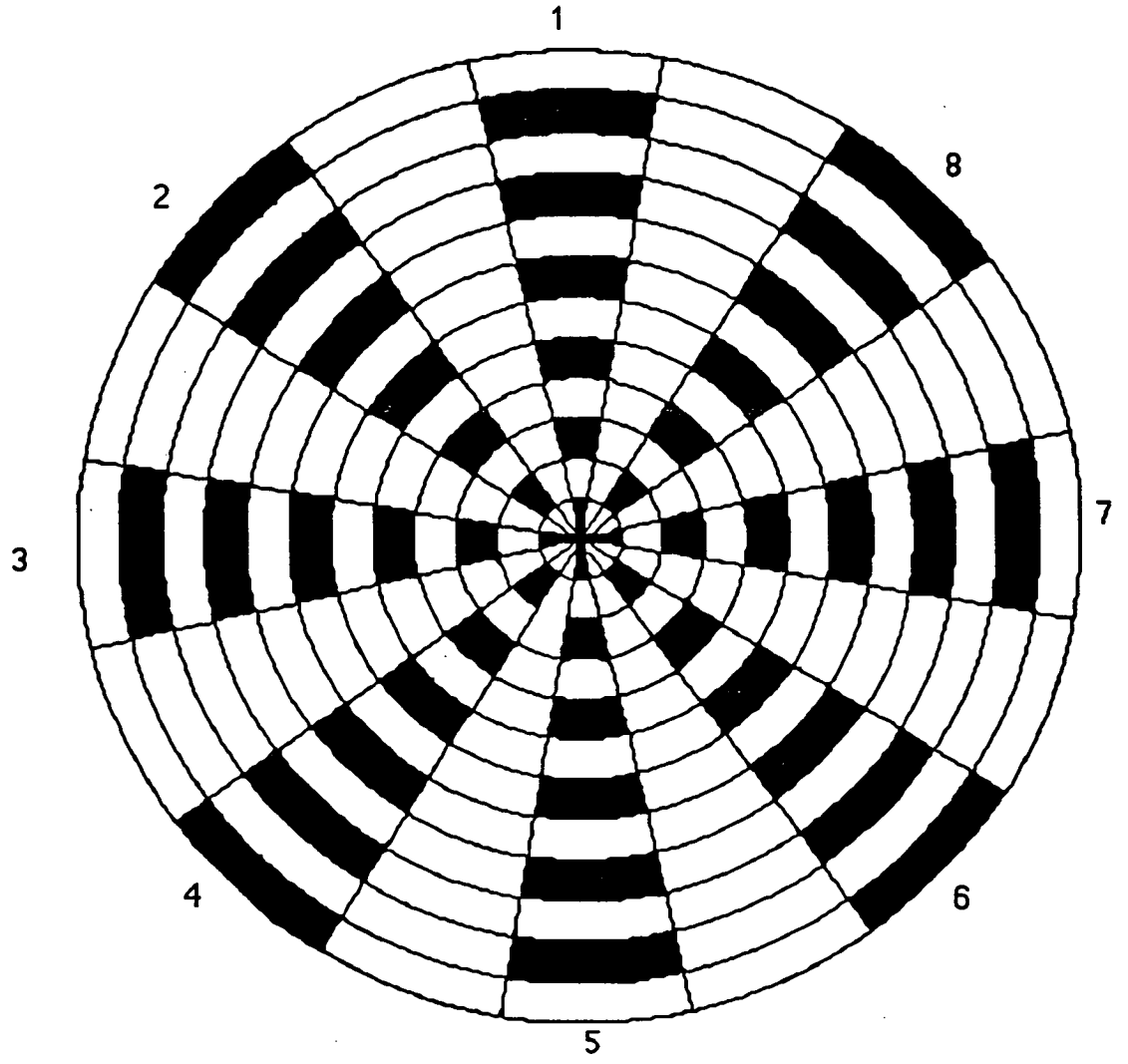
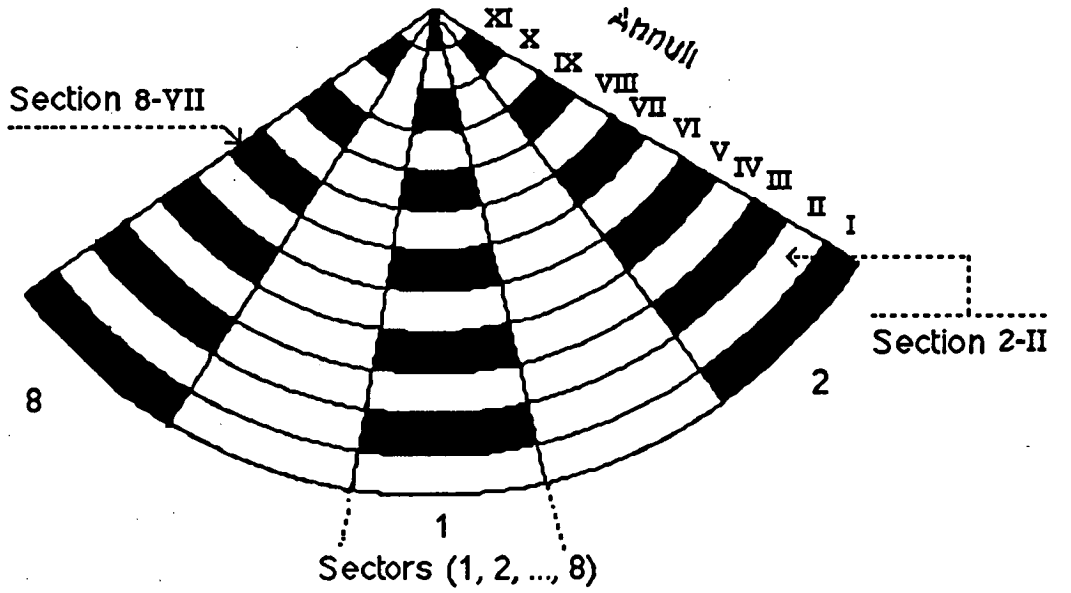


Fig. 4.3. The designation of sections.

In counting disc, black sections can be designated by the number

of the sector it is in and the number of the section itself.

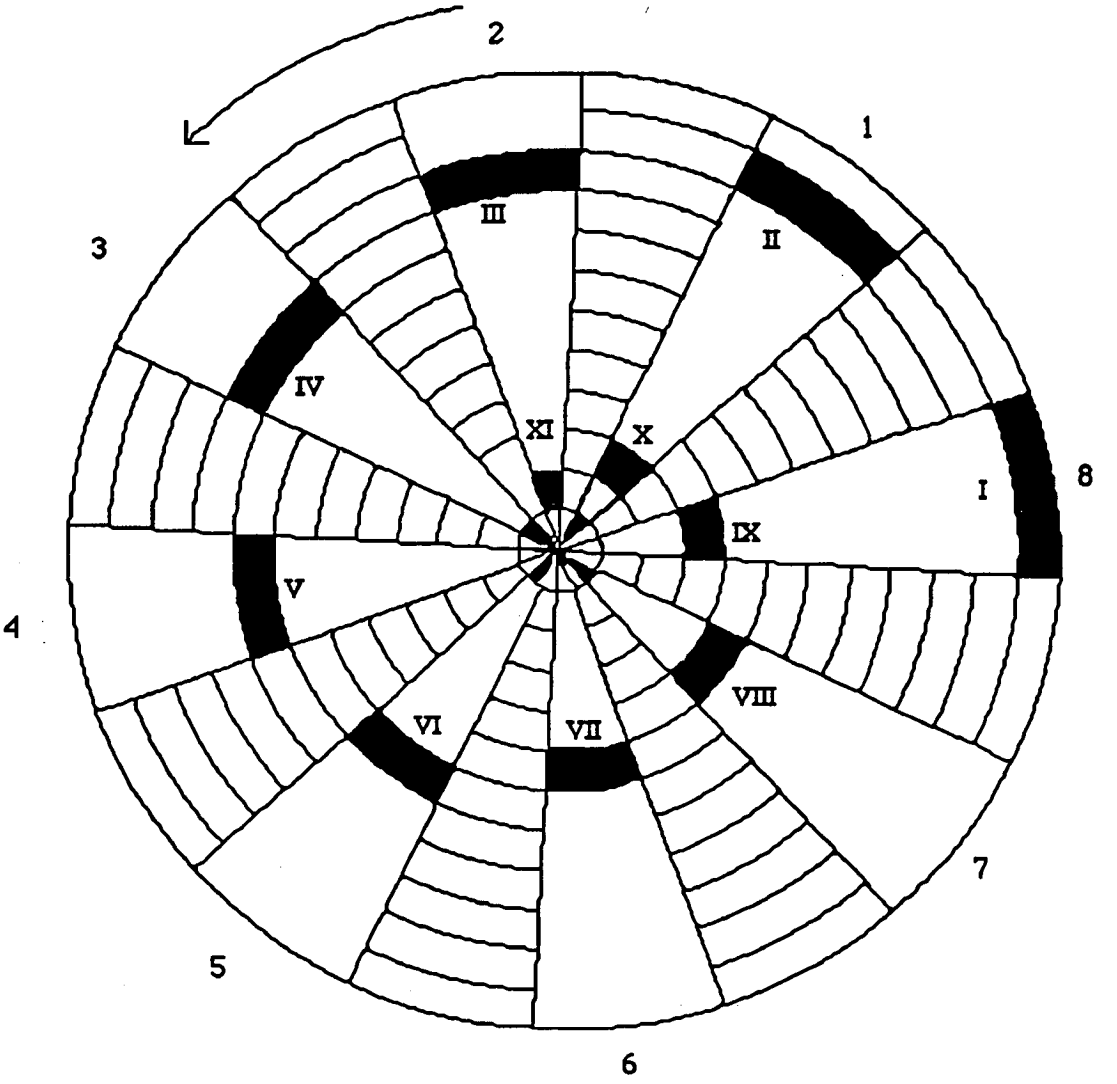


There were 4 replicate counting tracks each consisting of eleven black sections to be counted. (Table 4.1.). Thus every replicate counting track has an area equivalent to one sector.

Table 4.1. The composition of counting tracks.

Tracks	Count sequence									
8-2	8-I	1-II	2-III	3-IV	4-V	5-VI	6-VII	7-VIII	8-IX	1-X	2-XI
2-4	2-I	3-II	4-III	5-IV	6-V	7-VI	8-VII	1-VIII	2-IX	3-X	4-XI
4-6	4-I	5-II	6-III	7-IV	8-V	1-VI	2-VII	3-VIII	4-IX	5-X	6-XI
6-8	6-I	7-II	8-III	1-IV	2-V	3-VI	4-VII	5-VIII	6-IX	7-X	8-XI

Fig. 4.4. Sections to be counted in one counting track in the modified counting method.



Glass plates, in the same size and shape as the counting disc, were smeared with a thin layer of a mixture of glycerol and liquid detergent (3:1)

to collect the dislodged mites.

Sampling was made from five height strata* on one hop plant on Jan. 17, 1987. A single leaf was collected from each of the three strings within each height stratum. Each batch of three leaves was placed in a plastic bag and brought back to the laboratory for examination. All the leaves were of an equivalent size.

When the brushing machine was applied, the leaves were usually torn into 3 parts to ensure that all the leaf surfaces made contact with the brushes. Before each glass plate was removed after brushing, the inner surface of the metal cylinder was cleaned with a small brush with the glass plate still revolving to maximize mite collection on the plate.

One glass plate was used for all three leaves from each height division. There were five plates of mites altogether for this single hop plant. Each glass plate of mites was fixed on top of the counting disc by double-sided sticky tape and was examined with a binocular microscope at 20-fold magnification.

The "modified counting method" was applied to every plate, i.e., for every stratum. The numbers of eggs, larvae plus nymphs, adult males and females were counted and recorded separately**. As the number of adult males was usually very low, and also mites in this stage are not distinctive, they were counted with the larvae and nymphs. This inclusion was practised throughout the whole study.

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*: It was known that the distribution of mites was vertically varible. Therefore, the dividing of height will provide more accurate information of different mite densities (see Chapter 5).

**: This separation made it possible to monitor and evaluate the population growth and the impact of different mite stages (see Chapter 5).

4.2.1.2. Testing the "modified counting method"

Leaves were sampled from another partitioned six hop plants in the same way as described in 4.2.1.1., on January 17, 1988.

Leaves were examined directly first with a binocular microscope at 15-fold magnification and the density of different mite stages was recorded separately. Then all the mites on three leaves were removed using the mite brushing machine. In practice, mites from the 3 leaves of the same hop stratum of one plant were collected on a single glass plate and then counted under a binocular microscope at 20-fold magnification using the counting track of 8-2. The number of various mite stages was recorded separately, then multiplied by 16 to provide the total on that disc. A total of 84 leaves and 28 plates were examined.

4.2.2. Counting Mites Directly with the Naked Eye in the Field

On December 2, 11, 1987 and January 17, 1988, mites counting was made in the field. The number of adult females on a single leaf was counted directly with the naked eye and recorded. The sampled leaf was placed in a single plastic bag and brought to the laboratory in an ice chest. The leaves were examined again under a binocular microscope at 20-fold magnification and the number of mites in the various stages recorded.

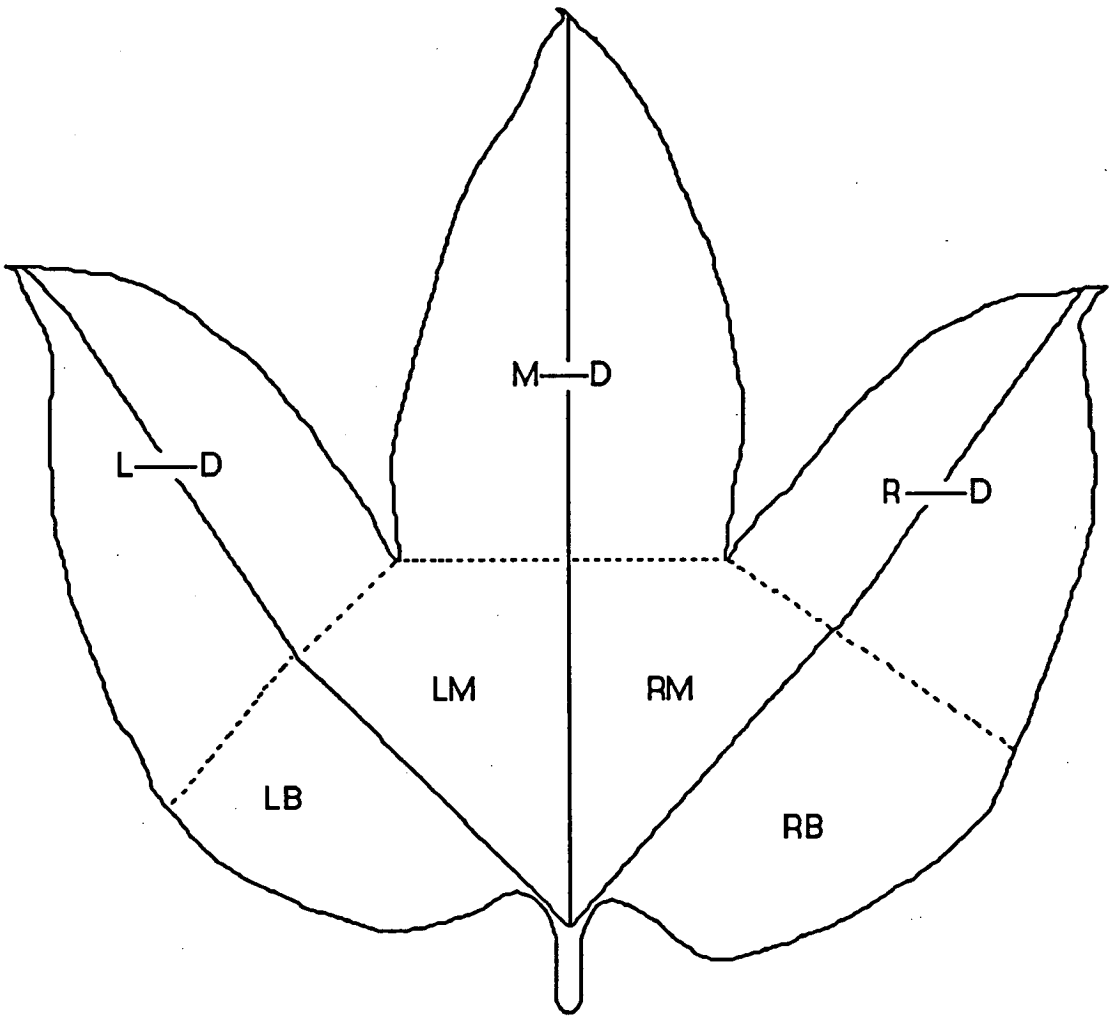
4.2.3. Investigating the Distribution of Mites on Single Hop Leaves

According to its configuration and venation, hop leaves can be artificially divided into various regions, as shown in Fig. 4.5..

Leaf samples were collected on November 8, 18, and December 3, 1987 to investigate the distribution patterns of mites on single leaves. Every individual leaf was placed in one plastic bag and brought to the laboratory

Fig. 4.5. Delineation of surface areas for sampling of mites on hop

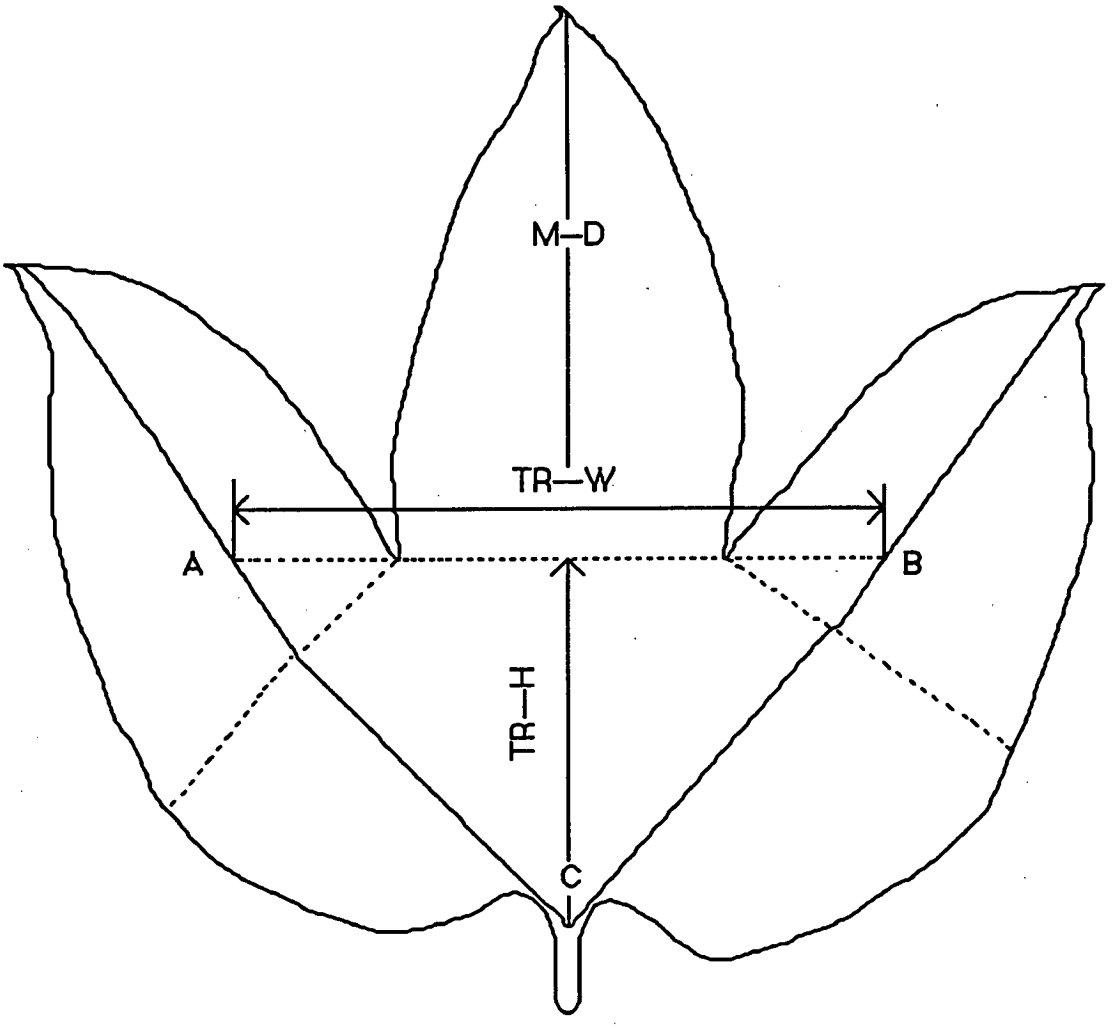
leaves.



L: left; R: right; M: middle; D: distal; B: basal.

Solid lines: leaf veins; dotted lines: fictitious division lines for regions.

Fig. 4.6. Dimensions of the fictitious triangle.



TR—W: the base of the fictitious triangle ΔABC;

TR—H: the height of the triangle ΔABC.

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in an ice chest. The sample leaves were kept in a -20°C freezing room overnight to prevent mites from wandering. Mite counts were made on the following day and the number of different stages on the different regions of leaf recorded separately.

Meanwhile, leaf areas were obtained with a planimeter (Paton Electronic

Planimeter) and the parameters as designated in Fig. 4.6. were measured before the leaf was run through the planimeter.

4.2.4. Data Analyses

In all analyses, the numbers of mites/section were treated as samples, then individual annuli, counting tracks, singly or in combination were considered as population samples respectively.

According to Southwood (1978, P.27) and Zar (1974, P.304), if the coefficient of dispersion (variance, s^2 /mean)is less than 1, then the distribution is uniform or even; if larger than 1,then contagious; if equal to 1, then random. Thus the coefficient of dispersion and the coefficient of variation were calculated for the data in 4.2.1.1.. All the data were analysed by one way analysis of variance (Zar 1984, pp. 162-167) and simple linear regression methods (Zar 1984, pp. 261-289). The calculations were completed on Macintosh SE with MacSoftware Statview SE + Graphics.

4.3. RESULTS

4.3.1. The Distribution of Mites on Counting Discs

Records of the counts of mites on discs, together with the coefficient of dispersion, coefficient of variation for annuli, are presented in Appendix 4.1. (A., B., C., and D.) for different mite stages and hop height divisions.

4.3.1.1. Eggs, larvae plus nymphs, and adult females

The coefficient of variation and coefficient of dispersion for eggs in different count tracks on one counting disc are given in Table 4.2., arranged according to height intervals of the hop plant. Eggs were found uniformly distributed on counting disc among black sections of each annulus, for the

C.D.'s of annuli for the five discs of mites (different height intervals and with various densities) were all less than 1 (Appendix 4.1., A.) This indicates that the number of eggs in a given annulus may be estimated from the number of eggs in sample sections within that annulus.

ANOV was carried out for every height interval separately and the results are presented in Table 4.2.. It was shown that the mean number of eggs per section obtained from the four count tracks can be accepted as equal to each other with high probabilities. Therefore, the variation of the number of eggs from the four tracks are not significant. This suggests that following a density estimate from only one count track would provide an adquate estimation of densities for all the four tracks and, in turn the entire disc. From the table, it is obvious that as the density of eggs increased with the plant height, the coefficient of variation decreased. The relationship between the mean numbers of eggs and the coefficients of variation is shown in Fig. 4.7..

Table 4.2. Data analyses for eggs on counting disc.

For height 0-90 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	37	3.36	3.04	1.74	0.90	52
2-4	11	43	3.91	2.39	1.55	0.61	40
4-6	11	46	4.18	3.92	1.98	0.94	47
6-8	11	50	4.55	3.08	1.75	0.68	39

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	406	43	
Between Group	8.182	3	2.727
Within Group	397.818	40	9.945

F = group MS / error MS = 0.274

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.8436

For height 90-180 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	59	5.36	2.98	1.73	0.56	32
2-4	11	55	5	3.98	1.99	0.80	40
4-6	11	62	5.64	3.11	1.76	0.55	31
6-8	11	66	6	3.67	1.91	0.61	32

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	483	43	
Between Group	5.909	3	1.97
Within Group	477.091	40	11.927

F = group MS / error MS = 0.165

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.9192

For height 180-270 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	111	10.09	6.12	2.48	0.61	25
2-4	11	117	10.64	7.43	2.73	0.70	26
4-6	11	93	8.46	5.03	2.24	0.60	27
6-8	11	104	9.46	4.03	2.01	0.43	21

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	1371.886	43	
Between Group	28.977	3	9.659
Within Group	1342.909	40	33.573

F = group MS / error MS = 0.288

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.834

For height 270-360 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	357	32.46	18.50	4.3	0.57	13
2-4	11	402	36.55	18.45	4.30	0.51	12
4-6	11	337	30.64	13.18	3.63	0.43	12
6-8	11	291	26.46	14.00	3.74	0.53	14

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	11096.977	43	
Between Group	578.25	3	192.75
Within Group	10518.727	40	262.968

F = group MS / error MS = 0.733

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.5385

For height 360-550 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	369	33.55	16.39	4.05	0.49	12
2-4	11	415	37.73	24.84	4.98	0.66	13
4-6	11	411	37.36	22.69	4.76	0.61	13
6-8	11	369	33.55	16.68	4.08	0.50	12

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	16962.909	43	
Between Group	176.727	3	58.909
Within Group	16786.182	40	419.655

F = group MS / error MS = 0.140

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.9352

Fig. 4.7. The relationship of mean number of eggs per section to the coefficient of variation.

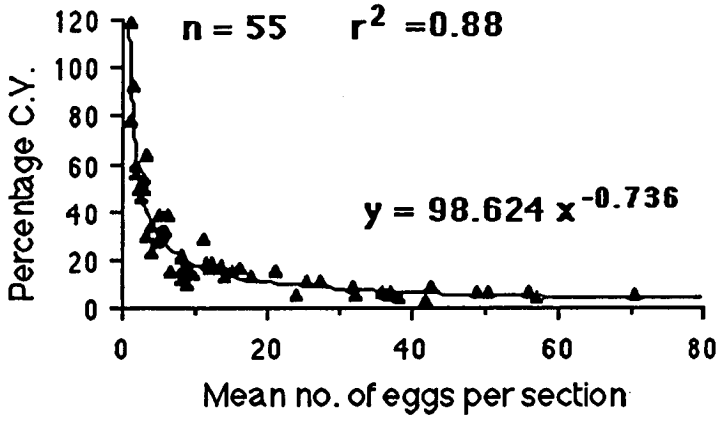
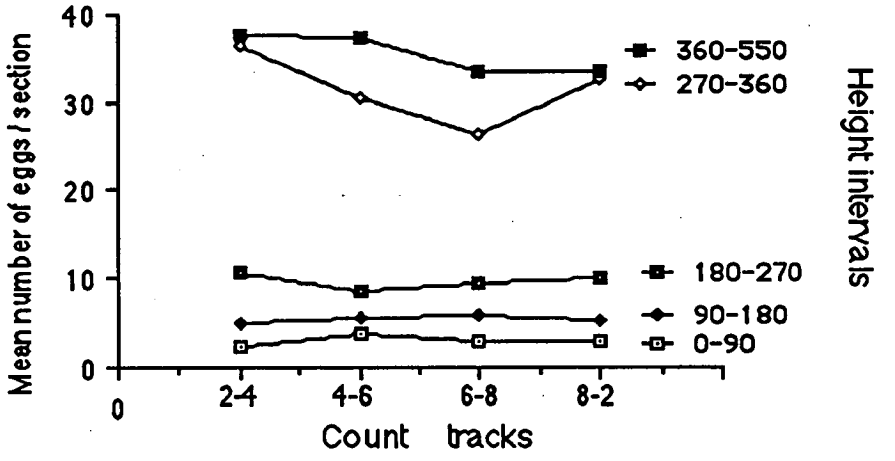


Fig. 4.8. Mean numbers of eggs (a) and coefficients of dispersion (b) for different count tracks on disc and at different height intervals for hop plants.

a. The comparison of egg means.



b. The comparison of coefficient of dispersion.

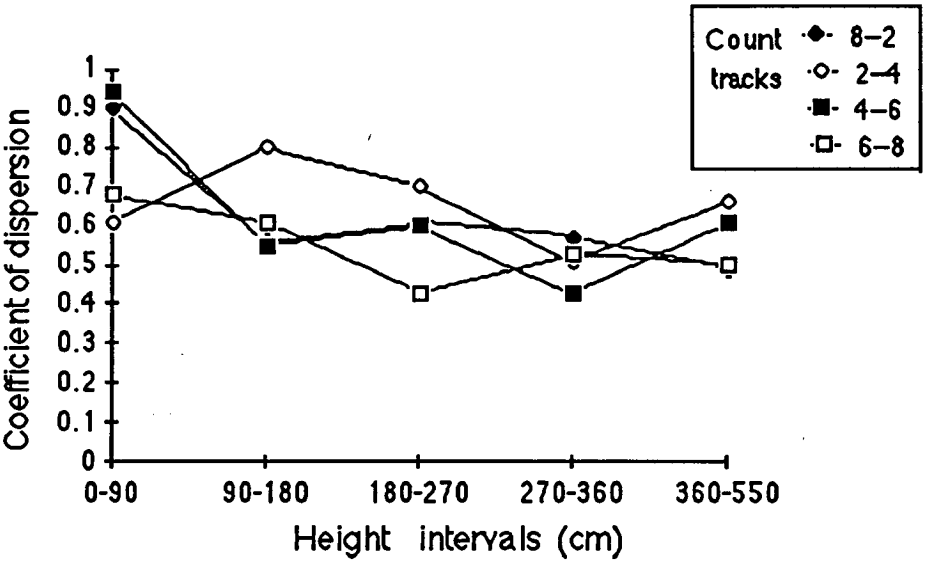


Fig. 4. 8. demonstrated that there was little variation of the mean number of eggs per section between the different counting tracks for a given hop height interval, this is in agreement of the results of one-way ANOV. It also showed that although the mean number of eggs per section was highly variable between hop height intervals, the coefficients of dispersion for

them were approximately same.

Table 4.3. Data analyses for larvae plus nymphs on counting disc.

For height 0-90 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	49	4.46	2.66	1.63	0.60	37
2-4	11	53	4.82	2.14	1.46	0.44	30
4-6	11	54	4.91	2.43	1.56	0.49	32
6-8	11	58	5.27	3.93	1.98	0.75	38

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	333.182	43	
Between Group	3.727	3	1.242
Within Group	329.445	40	8.236

F = group MS / error MS = 0.151

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.9285

For height 90-180 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	111	10.09	6.12	2.48	0.61	25
2-4	11	85	7.73	4.13	2.03	0.53	26
4-6	11	96	8.73	4.78	2.19	0.55	25
6-8	11	99	9	5.27	2.30	0.59	26

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	1082.432	43	
Group	31.159	3	10.386
Error	1051.273	40	26.282

F = group MS / error MS = 0.395

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.7571

For height 180-270 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	276	25.09	14.71	3.84	0.59	15
2-4	11	287	26.09	17.23	4.15	0.66	16
4-6	11	254	23.09	11.18	3.34	0.48	15
6-8	11	270	24.55	11.44	3.38	0.47	14

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	7741.159	43	
Between Group	51.705	3	17.235
Within Group	7689.455	40	192.236

F = group MS / error MS = 0.09

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.9653$

For height 270-360 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	459	41.73	23.52	4.85	0.56	12
2-4	11	398	36.18	21.59	4.65	0.60	13
4-6	11	411	37.36	15.62	3.95	0.42	11
6-8	11	352	32	17.5	4.18	0.55	13

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	16226.545	43	
Between Group	528.182	3	176.061
Within Group	15698.364	40	392.459

F = group MS / error MS = 0.449

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.7197$

For height 360-550 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	197	17.91	11.12	3.34	0.62	19
2-4	11	189	17.18	8.94	2.99	0.52	17
4-6	11	198	18.0	10.89	3.30	0.61	18
6-8	11	174	15.82	10.01	3.16	0.63	20

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

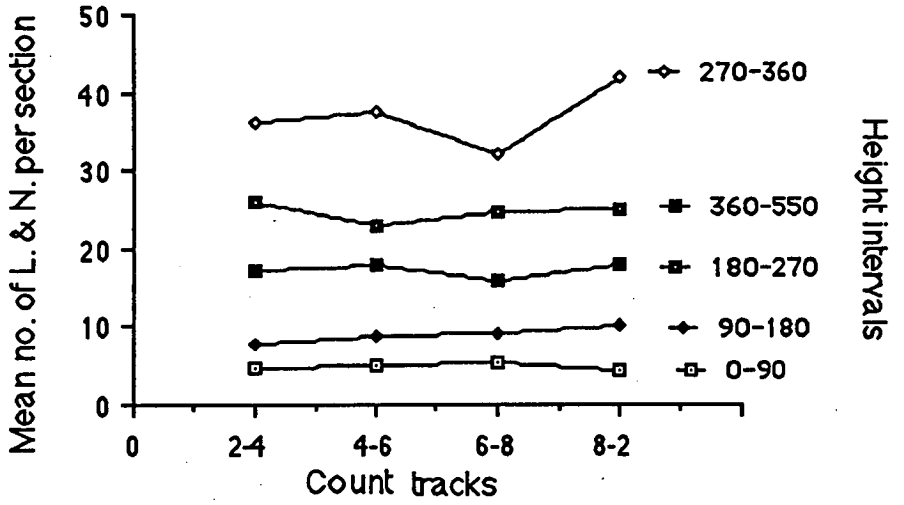
Source of variation	SS	DF	MS
Total	4257.727	43	
Between Group	33.545	3	11.182
Within Group	4224.182	40	105.605

F = group MS / error MS = 0.106

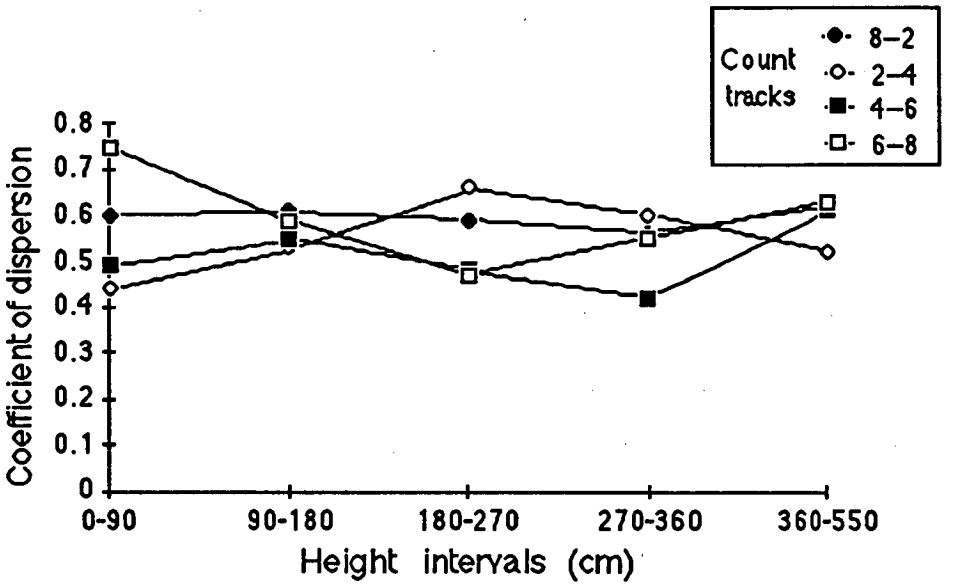
$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.9562$

Fig. 4. 9. Mean numbers of larvae and nymphs (a) and coefficients of dispersion (b) for different count tracks on disc and at different height intervals.

a. The comparison of mean number of larvae and nymphs.



b. The comparison of coefficient of dispersion.



Similar results were obtained for larvae and nymphs (Table 4.3., Fig. 4.9.), that is, larvae & nymphs were also uniformly distributed among sections within each annulus, within each count track, and among sections on the

that is, larvae & nymphs were also uniformly distributed among sections within each annulus, within each count track, and among sections on the whole disc. The relationship between means and the coefficient of variation for larvae and nymphs is shown in Fig. 4.10..

For adult females, the distributions among sections between annuli, within counting tracks, or on the whole disc, were obviously not uniform, but contagious (C.D.'s > 1). This probably was caused by the low number of adult female mites present on the counting disc. However, there were no significant differences between mean mite densities of the 4 different counting tracks (Table 4.4.). The relationship between mean and the coefficient of variation is similar to the results obtained previously for eggs, larvae and nymphs, and is shown in Fig. 4.11.. The coefficient of dispersion varied greatly among hop height intervals of 0-90, 90-180, 180-270, but became constant, around 1, in the height intervals of 270-360 and 360-550. (Fig. 4.12.).

Fig. 4. 10. The relationship between mean number of larvae and nymphs per section and the coefficient of variation.

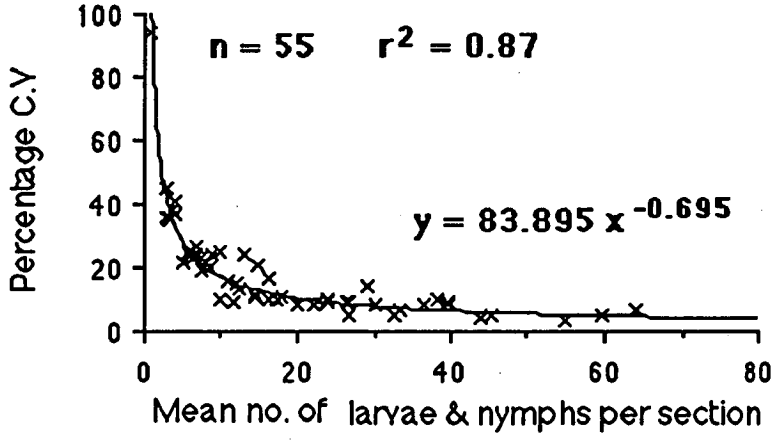


Table 4. 4. Data analyses for adult female mites on counting disc.

For height 0-90 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	1	0.09	0.30	0.55	3.32	604
2-4	11	1	0.09	0.30	0.55	3.32	604
4-6	11	0	0	-	-	-	-
6-8	11	1	0.09	0.30	0.55	3.32	604

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	2.795	43	
Between Group	0.068	3	0.02
Within Group	2.727	40	0.068

F = group MS / error MS = 0.333

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.8013

For height 90-180 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	1	0.09	0.30	0.55	3.32	604
2-4	11	1	0.09	0.30	0.55	3.32	604
4-6	11	1	0.09	0.30	0.55	3.32	604
6-8	11	1	0.09	0.30	0.55	3.32	604

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	3.636	43	
Between Group	0	3	0
Withn Group	3.636	40	0.091

F = group MS / error MS = 0

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0

For height 180-270 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	2	0.17	0.39	0.62	2.34	374
2-4	11	1	0.09	0.30	0.55	3.32	604
4-6	11	3	0.27	0.47	0.68	1.71	251
6-8	11	2	0.17	0.39	0.62	2.34	374

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	6.545	43	
Between Group	0.182	3	0.061
Within Group	6.364	40	0.159

F = group MS / error MS = 0.381

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 p = 0.7672

For height 270-360 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	8	0.73	0.65	0.80	0.89	111
2-4	11	7	0.64	0.81	0.90	1.27	141
4-6	11	6	0.55	0.69	0.83	1.26	152
6-8	11	6	0.55	0.69	0.83	1.26	152

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	1.432	43	
Between Group	0.0.25	3	0.083
Within Group	10.182	40	0.255

F = group MS / error MS = 0.327

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.8055$

For height 360-550 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	12	1.09	0.93	0.97	0.87	89
2-4	11	13	1.18	1.25	1.12	1.06	95
4-6	11	11	1	0.89	0.95	0.89	95
6-8	11	7	0.64	0.67	0.82	1.06	129

Table of ANOV

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	38.977	43	
Between Group	1.886	3	0.629
Within Group	37.091	40	0.927

F = group MS / error MS = 0.678

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.5706$

Fig. 4. 11. The relationship between mean numbers of adult female mites per section and the coefficients of variation.

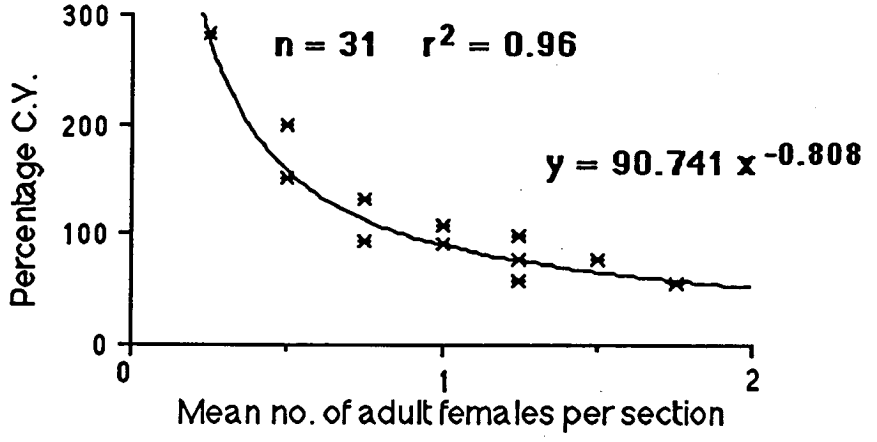
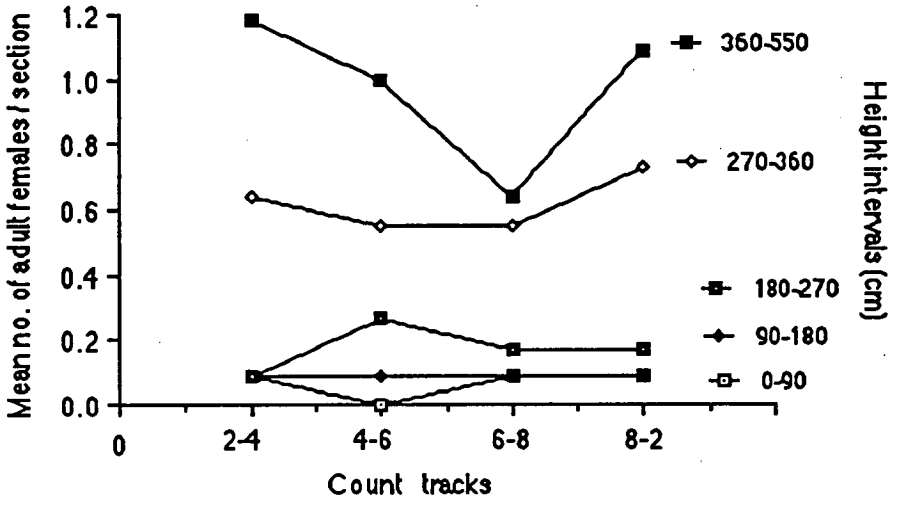
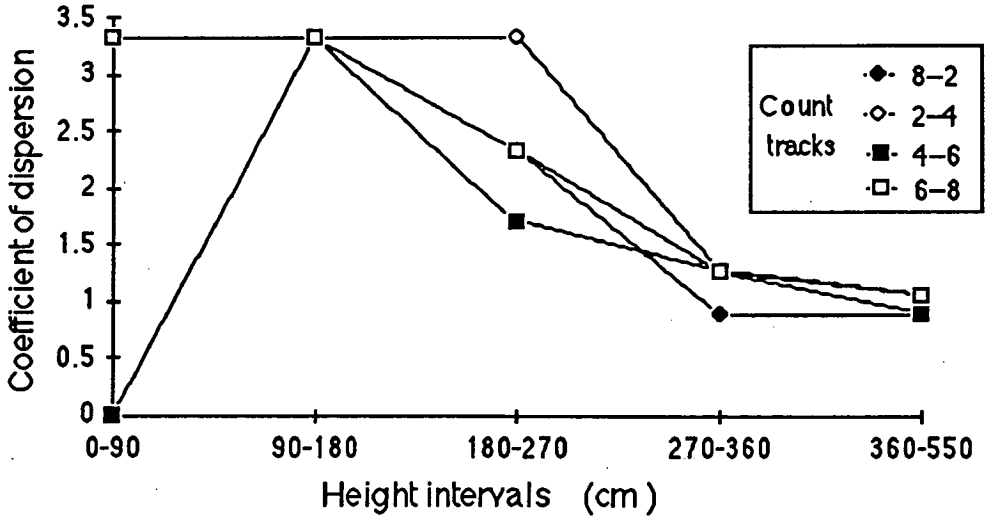


Fig. 4. 12. Mean numbers of adult females (a) and coefficient of dispersion (b) for different count tracks on disc and at different height intervals.

a. The comparison of mean numbers of adult females.



b. The comparison of coefficient of dispersion.



4.3.1.2. All mite stages

When the number of all stages of mites were considered together, the same statistical procedure yielded similar results (Table 4.5.). The mites were uniformly distributed among sections within every annulus, every counting track, and on the whole disc. There were no significant differences between means from different counting tracks within a given height interval. Fig. 4.13. again revealed the relationship between mean and the coefficient of variation. It was found that the distribution of mites on the counting disc was fairly constant (Fig. 4.14.). Fig. 4.15. showed that the percentage mean number of mites in sections for one count track (8-2) was almost the same at different height intervals, even though the mean densities were different between these heights, indicating that the patterns of the dispersion of dislodged mites on the counting disc are identical despite the different densities once a bare level of abundance occurred on the disc. The distribution of mites among sections within each count track for various heights is presented in Fig. 4.16.. Generally, sections 3, 4, and 5 received the most mites, neverthless, mites can still be considered as being uniformly distributed. The coefficient of dispersion for mites on a disc hardly varied between height divisions, although the means were significantly different (Fig. 4.17.).

Table 4. 5. Data analyses for all mite stages on counting disc.

For height 0-90 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	87	7.91	4.83	2.20	0.61	28
2-4	11	97	8.82	3.92	1.98	0.44	23
4-6	11	100	9.09	5.87	2.42	0.65	27
6-8	11	109	9.91	6.66	2.58	0.67	26

Table of ANOV for count tracks

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	1196.8	43	
Group	22.43	3	7.48
Error	1174.37	40	29.36

F = group MS / error MS = 0.2548

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.8575$

Table of ANOV between annuli

H_0; $Mean_I = Mean_{II} = ... = Mean_X = Mean_{XI}$

Source of variation	SS	DF	MS
Total	1196.795	43	
Between Group	926.045	10	92.605
Within Group	270.75	33	8.205

F = group MS / error MS = 11.287

$F_{0.05\,(1),\,10,\,33} = 2.13$ Reject H_0 $p = 0.0001$

For height 90-180 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	171	15.55	8.25	2.87	0.53	19
2-4	11	131	11.91	6.52	2.55	0.55	21
4-6	11	159	14.46	6.74	2.60	0.47	18
6-8	11	167	15.18	8.95	2.99	0.59	20

Table of ANOV for count tracks

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	2450.73	43	
Group	88.73	3	29.58
Error	2362	40	59.05

F = group MS / error MS = 0.5018

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.6838$

Table of ANOV between annuli

H_0; $Mean_I = Mean_{II} = ... = Mean_X = Mean_{XI}$

Source of variation	SS	DF	MS
Total	2450.727	43	
Between Group	1775.727	10	177.573
Within Group	675	33	20.455

F = group MS / error MS = 8.681

$F_{0.05\,(1),\,10,\,33} = 2.13$ Reject H_0 $p = 0.0001$

For height 180-270 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	388	35.27	20.29	4.51	0.58	13
2-4	11	405	36.82	23.74	4.87	0.65	13
4-6	11	350	31.82	15.28	3.91	0.48	12
6-8	11	378	34.36	14.73	3.84	0.43	11

Table of ANOV for count tracks

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	14402.79	43	
Group	144.79	3	48.26
Error	14258	40	356.45

F = group MS / error MS = 0.1354

$F_{0.05\ (1),\ 3,\ 40} = 2.84$ Do not reject H_0 $p = 0.9383$

Table of ANOV between annuli

H_0; $Mean_I = Mean_{II} = ... = Mean_X = Mean_{XI}$

Source of variation	SS	DF	MS
Total	14402.795	43	
Between Group	12285.045	10	1228.505
Within Group	2117.75	33	64.174

F = group MS / error MS = 19.143

$F_{0.05\ (1),\ 10,\ 33} = 2.13$ Reject H_0 $p = 0.0001$

For height 270-360 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	824	74.91	41.59	6.45	0.56	9
2-4	11	807	73.36	39.47	6.28	0.54	9
4-6	11	754	68.55	27.34	5.23	0.40	8
6-8	11	650	59.00	30.90	5.56	0.52	9

Table of ANOV for count tracks

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	51574.98	43	
Group	1675.89	3	558.63
Error	49899.09	40	1247.48

F = group MS / error MS = 0.4478

$F_{0.05\ (1),\ 3,\ 40} = 2.84$ Do not reject H_0 $p = 0.7202$

Table of ANOV between annuli

H_0; $Mean_I = Mean_{II} = ... = Mean_X = Mean_{XI}$

Source of variation	SS	DF	MS
Total	51574.977	43	
Between Group	40571.227	10	4057.123
Within Group	11003.75	33	333.447

F = group MS / error MS = 12.167

$F_{0.05\ (1),\ 10,\ 33} = 2.13$ Reject H_0 $p = 0.0001$

For height 360-550 cm

Count tracks	No. of sections	Total mite	Mean mite	S^2	S	C.D.	C.V.
8-2	11	568	51.64	27.31	5.23	0.53	10
2-4	11	616	56.00	33.80	5.81	0.60	10
4-6	11	620	56.36	32.24	5.68	0.57	10
6-8	11	550	50.00	25.39	5.04	0.51	10

Table of ANOV for count tracks

H_0: $Mean_{8-2} = Mean_{2-4} = Mean_{4-6} = Mean_{6-8}$

Source of variation	SS	DF	MS
Total	36059	43	
Group	331.92	3	110.64
Error	35727.08	40	893.18

F = group MS / error MS = 0.1239

$F_{0.05\,(1),\,3,\,40} = 2.84$ Do not reject H_0 $p = 0.9455$

Table of ANOV between annuli

H_0; $Mean_I = Mean_{II} = ... = Mean_X = Mean_{XI}$

Source of variation	SS	DF	MS
Total	36059	43	
Between Group	32935.5	10	3293.55
Within Group	3123.5	33	94.652

F = group MS / error MS = 34.797

$F_{0.05\,(1),\,10,\,33} = 2.13$ Reject H_0 $p = 0.0001$

Fig. 4.13. The relationship between the mean numbers of all stages of mites per section and the coefficients of variation.

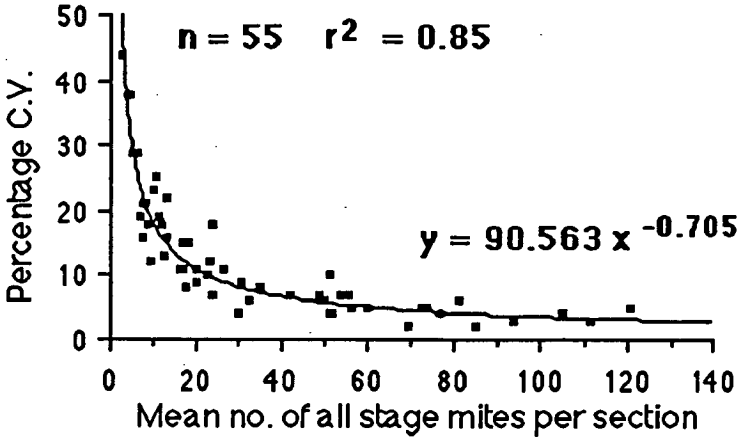
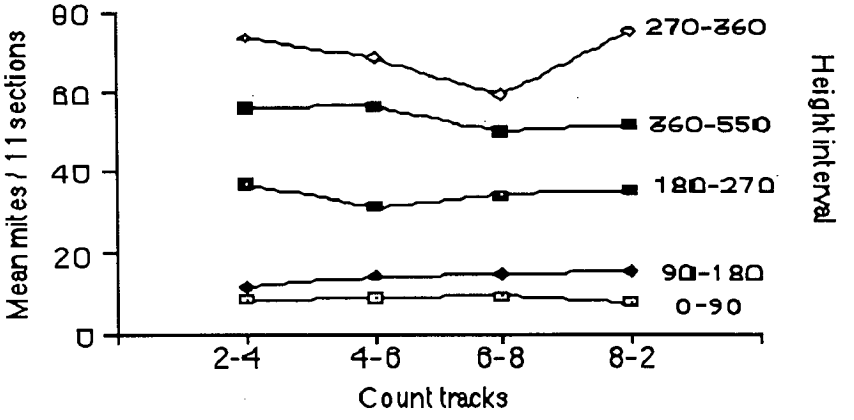


Fig. 4.14. Mean numbers of mites and coefficients of dispersion for different counting tracks and height intervals.

a. comparison of mean numbers of mites.



b. comparison of coefficients of dispersion.

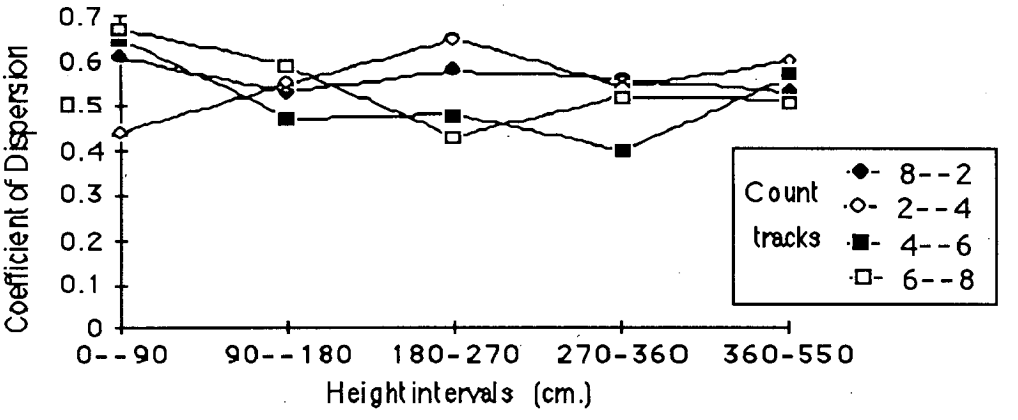


Fig. 4.15. Percentage means of mite number per section for various height intervals.

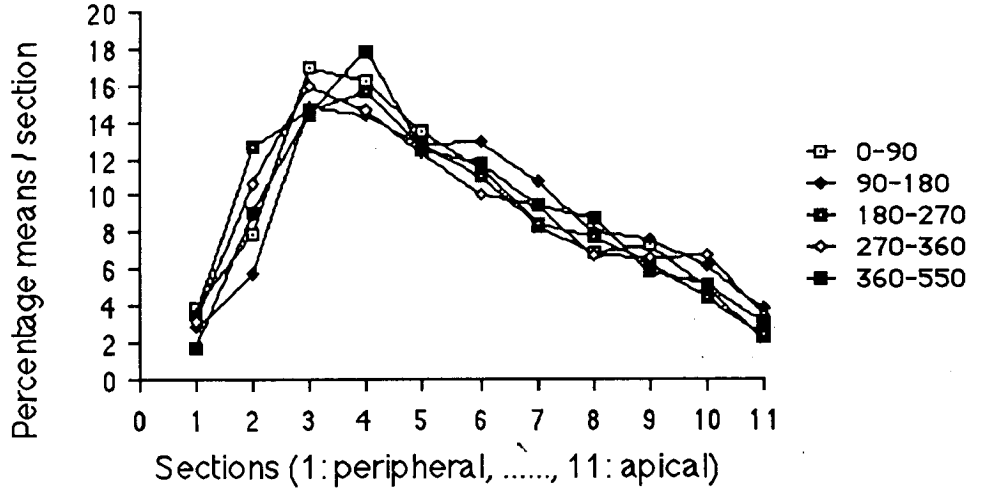


Fig. 4.16. Distributions of mites (all stages) among sections on disc, counted under different counting tracks, for various height intervals (Leaves were sampled on January 17, 1988).

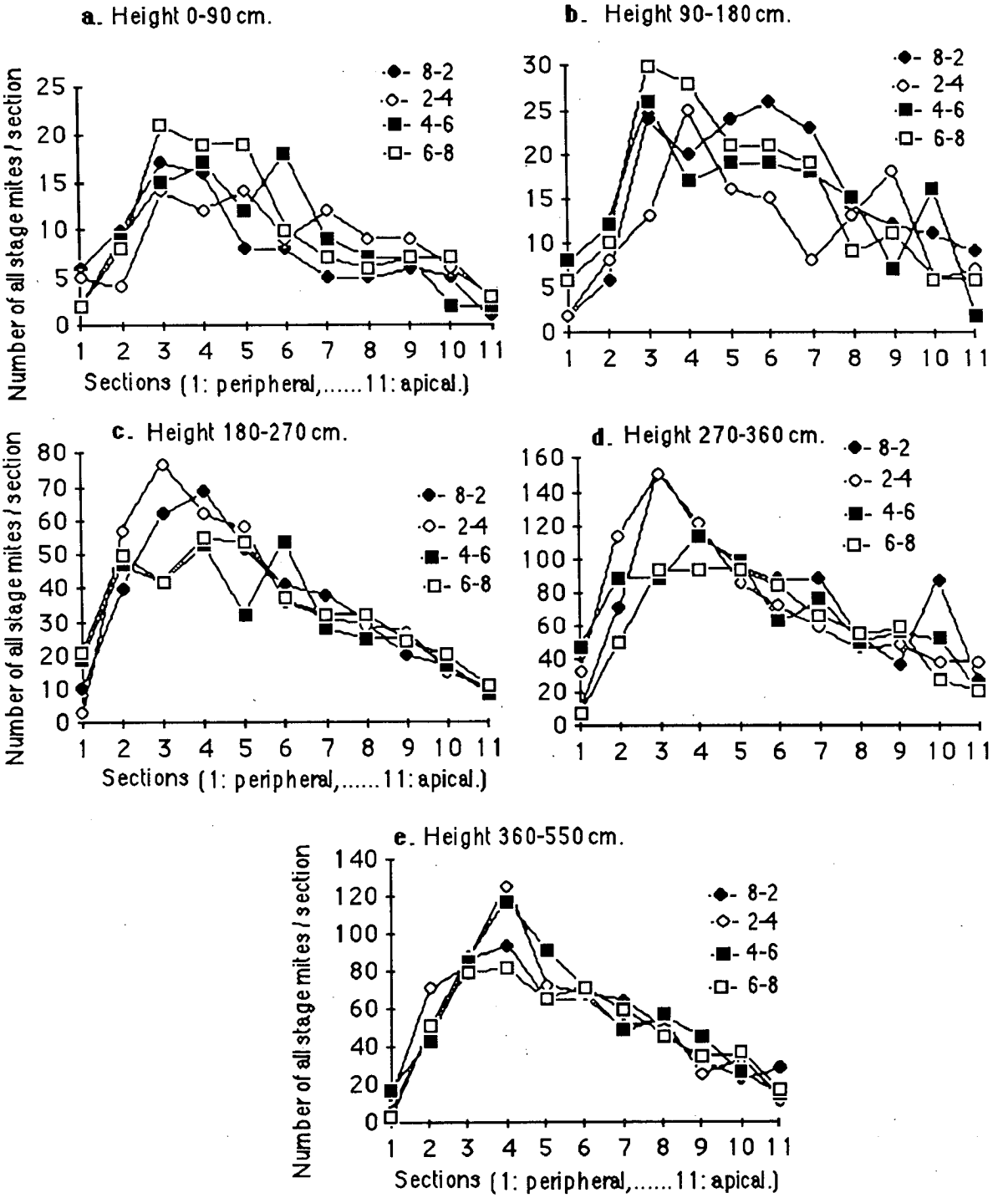
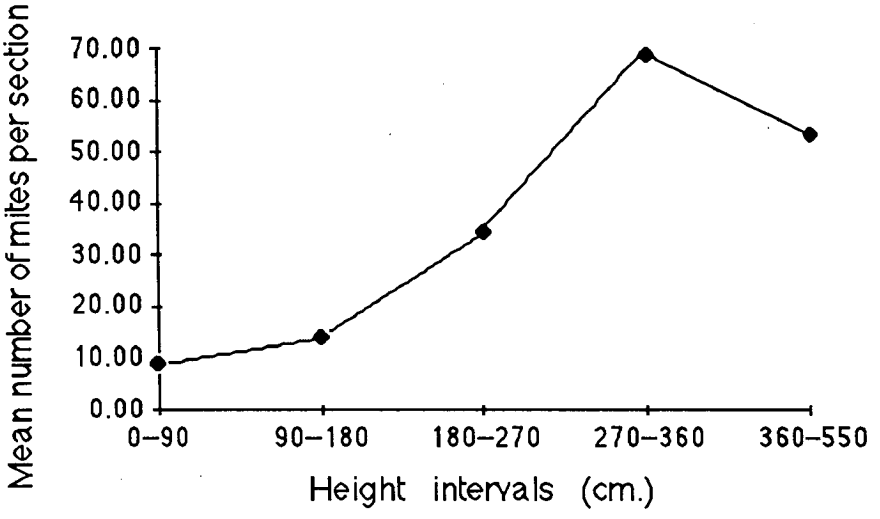
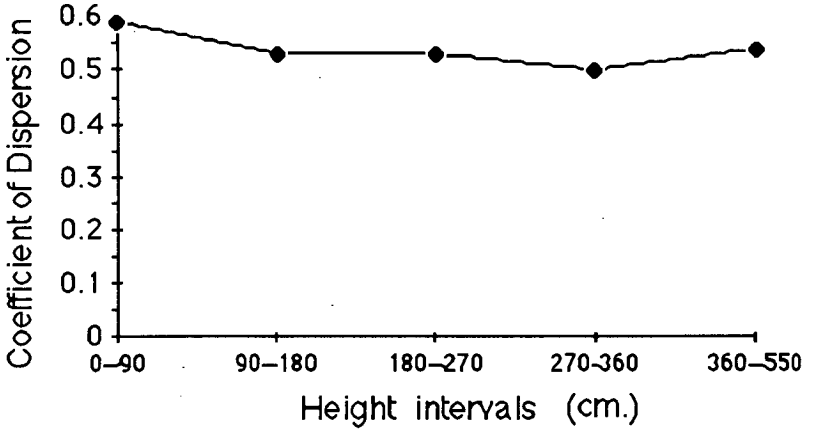


Fig. 4.17. Mean numbers of mites and coefficients of dispersion for various height interval of hop plant.

a. Mean numbers of mites on leaves sampled for different height levels and expressed as mites/section.



b. Coefficients of dispersion of mites on disc for various height levels.



4.3.2. Estimating Actual Mite Densities with the Modified Counting Method

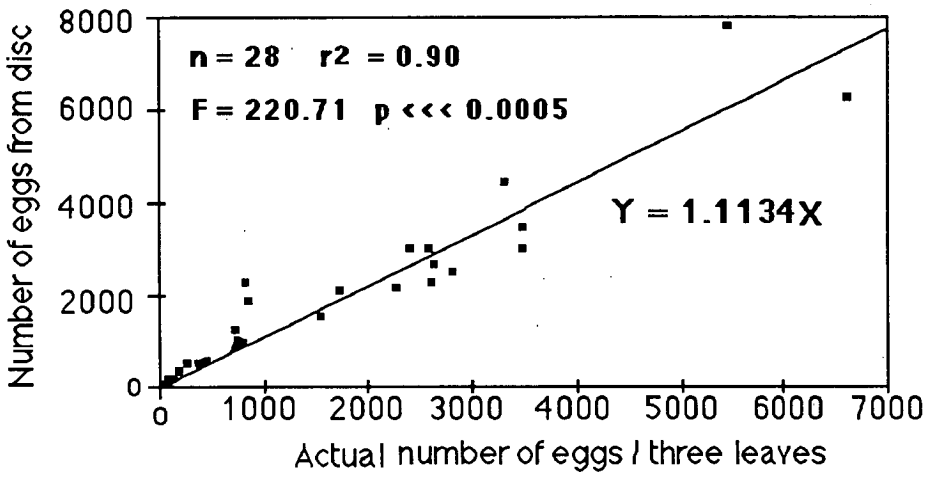
There was a very significant linear regression between the total number of eggs per disc, obtained from number of eggs on one counting track (8-2) multiplied by 16, and the total number of eggs on three leaves originally counted under the binocular. When the raw data were transformed by log (x+1), the coefficient of determination (r^2) was increased from 0.90 to 0.97 (Fig. 4.18.). Similar results were also obtained for the data of larvae plus nymphs (Fig. 4.19.). For adult females, the regression between untransformed data was sufficient (r^2 = 0.94), for data transformation actually decreased the coefficient of determination (r^2 = 0.77) (Fig. 4.20.).

When the total number of mites of various stages were combined together and compared, a most significant simple linear regression line was obtained (Fig. 4.21.).

The prediction of the actual number of all stage of mites from only the number of adult females resulted in a very significant linear regression following log transformation(Fig. 4.22.).

Fig. 4.18. Linear regression of numbers of eggs estimated from disc (Y) on the actual numbers of eggs counted from three hop leaves (X).

a. for the original data



b - for the transformed data

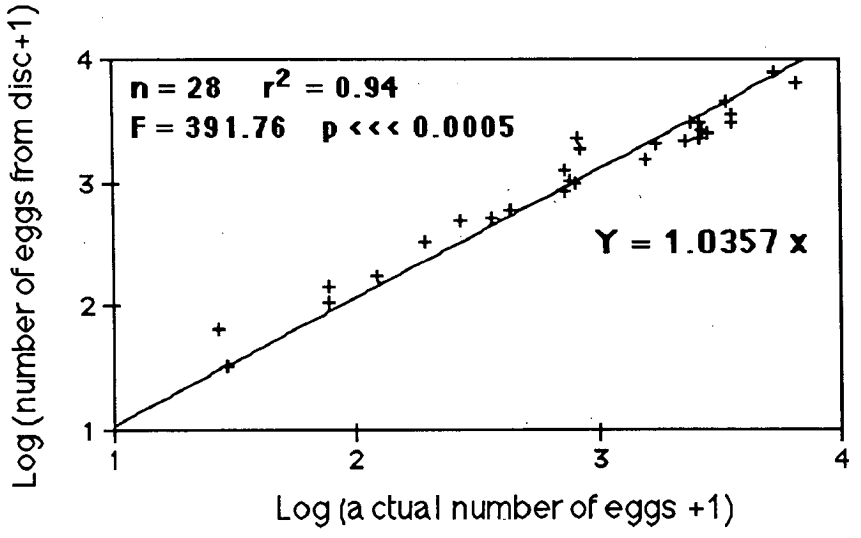
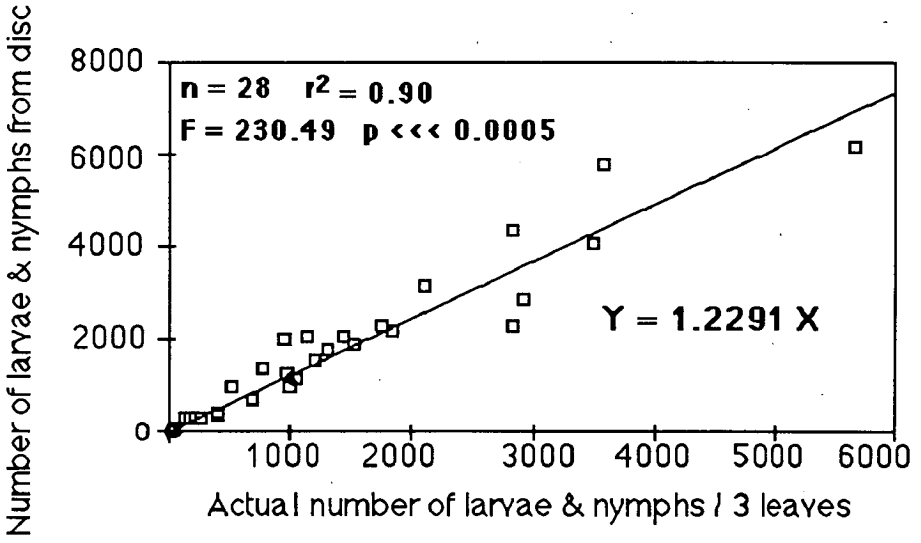


Fig. 4.19. Linear regression of numbers of larvae plus nymphs estimated from disc (Y) on the actual numbers of larvae plus nymphs counted from three hop leaves (X).

a. for the original data



b. for the transformed data

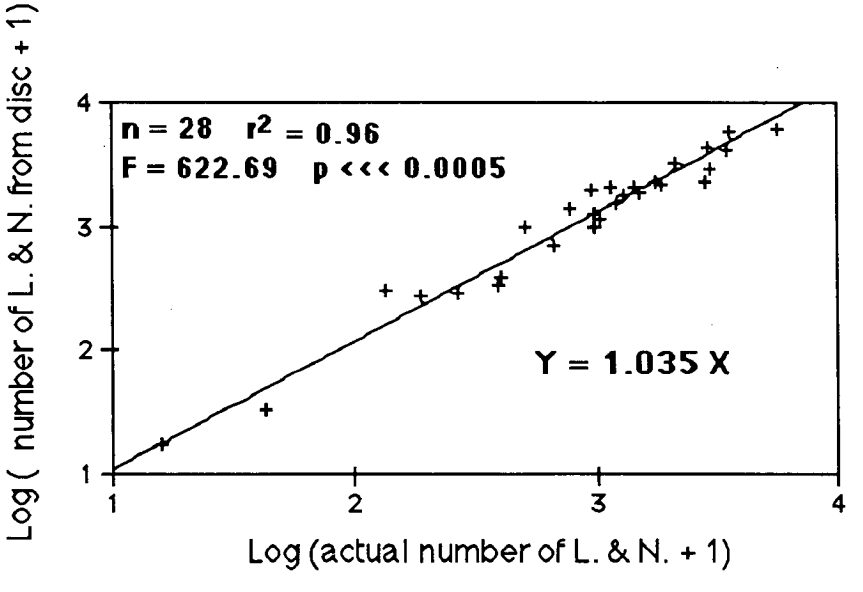
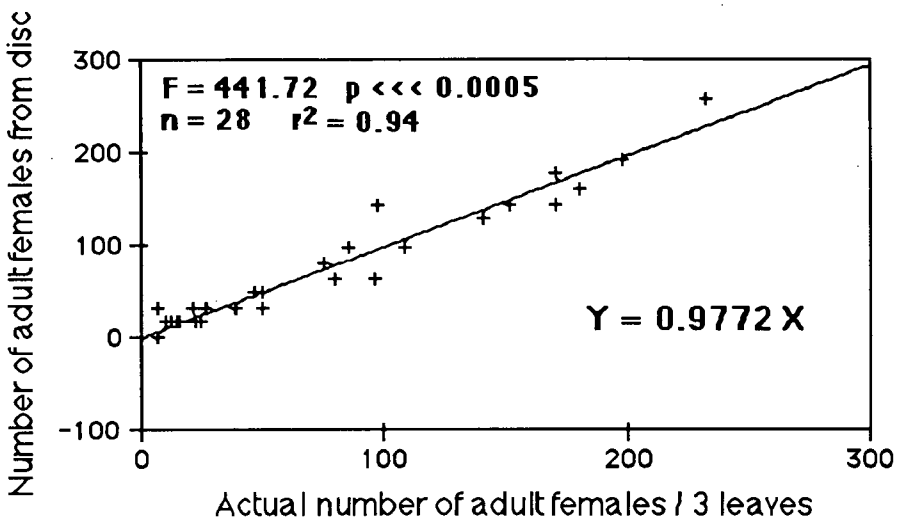


Fig. 4.20. Linear regression of numbers of adult female mites estimated from disc (Y) on the actual numbers of adult female mites counted from three leaves (X).

a. for the original data



b. for the transformed data

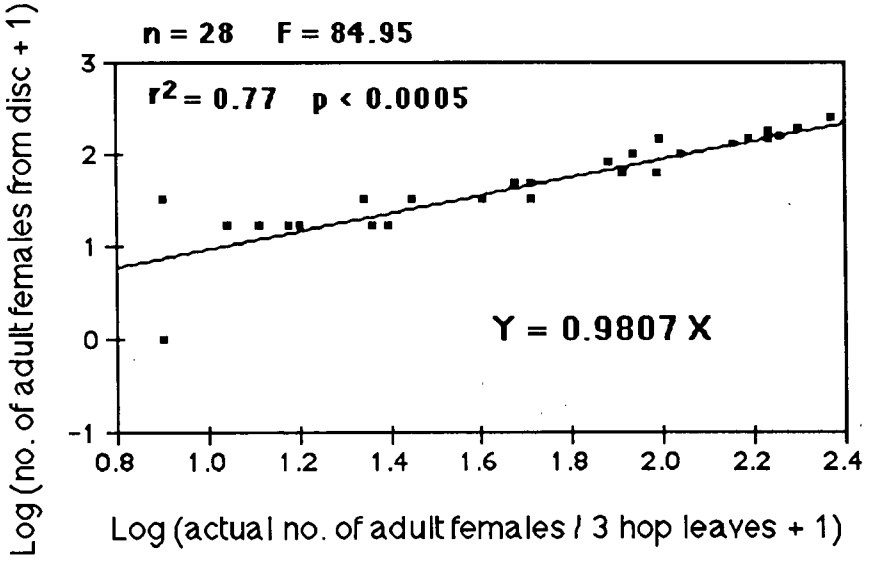
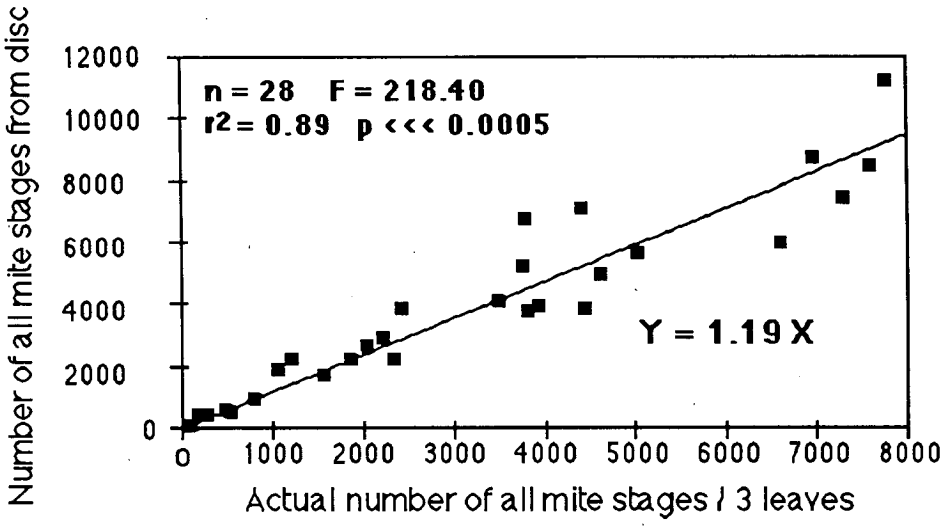


Fig. 4.21. Linear regression of numbers of all mite stages estimated from disc (Y) on the actual numbers of all mite stages counted from three hop leaves (X).

a. for the original data



b. for transformed data

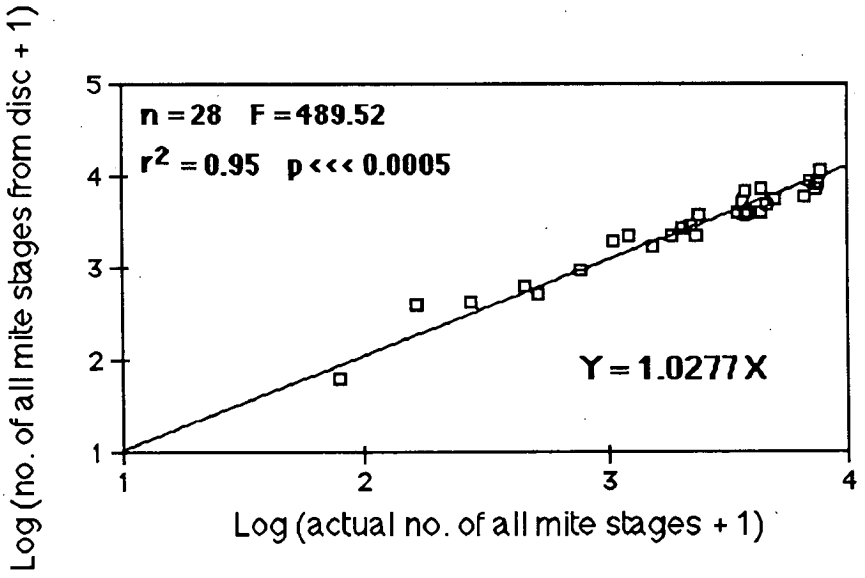
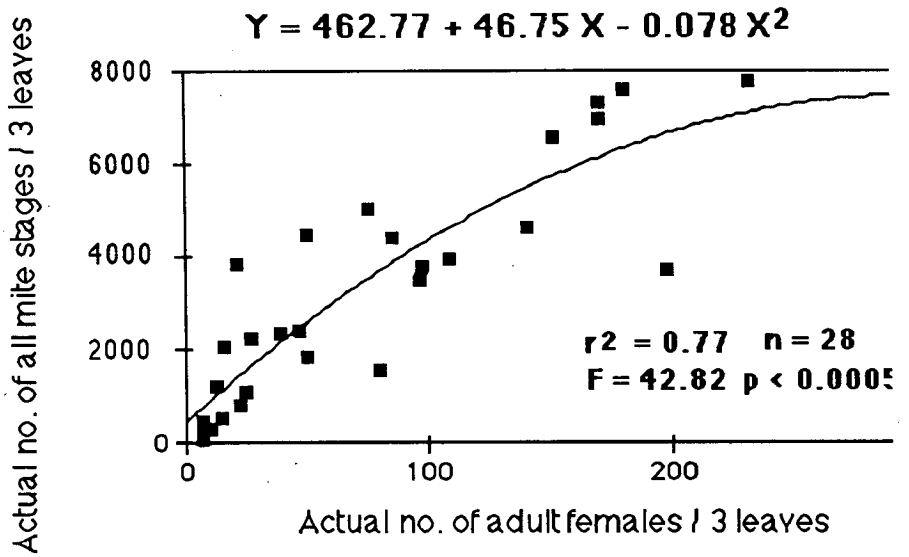
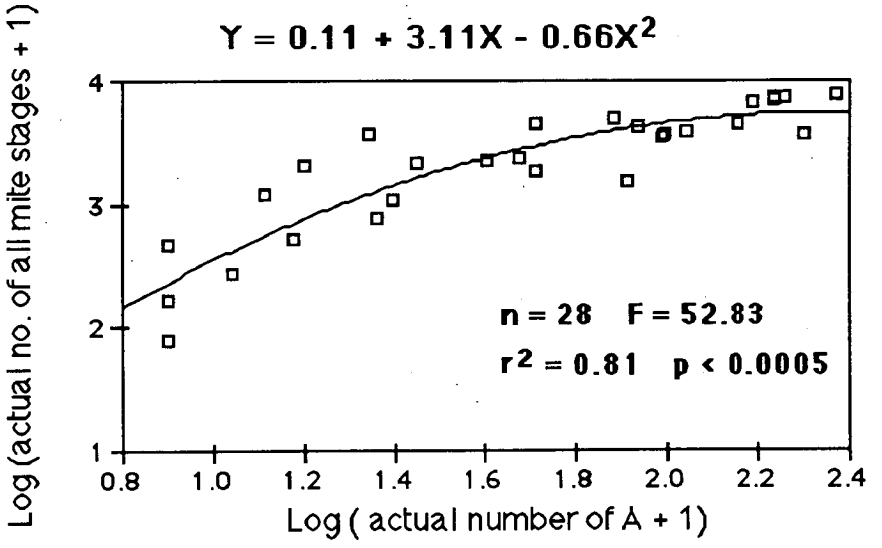


Fig. 4.22. Curvilinear relationship between the numbers of all stages of mites (Y) and numbers of adult female mites counted from three hop leaves (X).

a. quadratic regression for the original data



b. quadratic regression for transformed data



4.3.3. Assessing Mite Density Directly with the Naked Eye

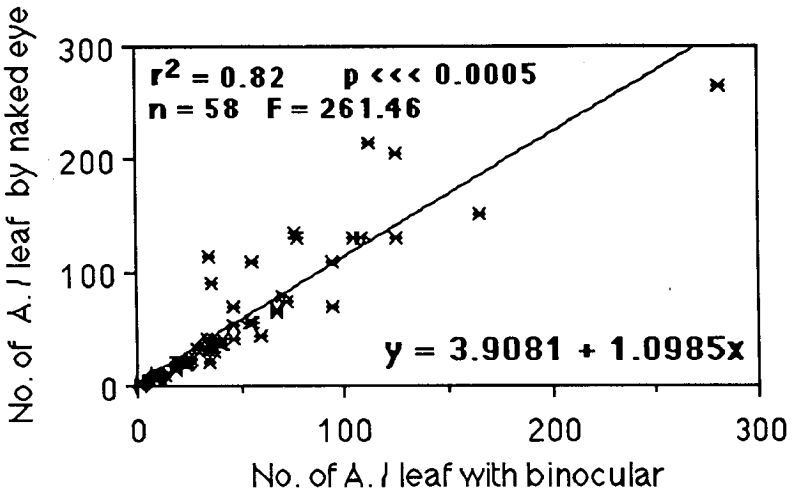
The actual numbers of female mites, obtained from direct counting in the field with the naked eye and counted in the laboratory beneath a binocular microscope is presented in Table 4.6.. A very significant linear regression line was fitted to the numbers of adult female mite densities obtained by the two different counting methods (Fig. 4.23.).

Table. 4. 6. The numbers of adult female mites recorded from two different counting methods.

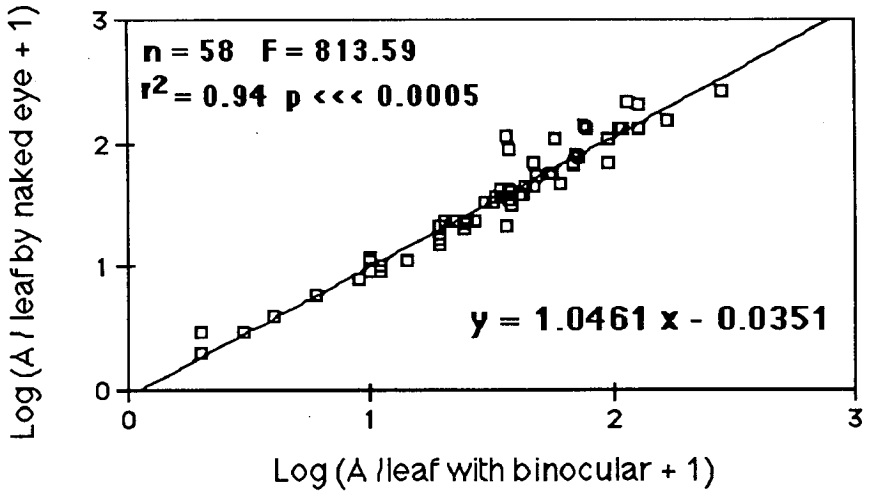
	Adult females per leaf			Adult females per leaf	
Date	No. counted by naked eye (estimate)	No. counted beneath binocular (actual)	Date	No. by naked eye (estimate)	No. beneath binocular (actual)
2/12/87	90	36	7/1/88	23	26
	80	70		2	1
	205	125		8	10
	115	35		31	37
	215	113		38	40
	110	94		22	19
	130	78		20	18
	130	108		9	10
	130	105		22	24
	70	46		43	42
	20	35		8	9
	110	56		34	36
	35	32		43	46
	130	126		19	23
	265	280		7	8
	65	67		33	31
	55	55		152	165
	135	76		75	72
	42	34		55	54
Dec. 11	53	47		37	41
	11	9		70	95
	22	21		10	13
	9	10		16	18
	40	37		21	23
	67	67		14	18
	1	1		33	29
	2	2		45	60
	10	9		5	5
	3	3			
	42	36			

Fig. 4.23. Linear regression of the number of adult female mites (A) counted by the naked eye in the field (y) on the number of adult female mites on hop leaves counted with binocular microscope (x).

a. for original data



b. for transformed data



4.3.4. The Distribution of Mites on Leaves and the Estimation of Mite Density

Appendix 4.2. presents the original record of the numbers of all stages of mites on the whole leaves, that on various parts (LM + RM, LM +RM +MD) of the leaves (A); the numbers of adult females and that of all stages of mites on whole leaves and the numbers of adult females in the fictious triangles (B); and the measures of leaf area, the length, width and area of the conceived triangle in the middle of leaves (C).

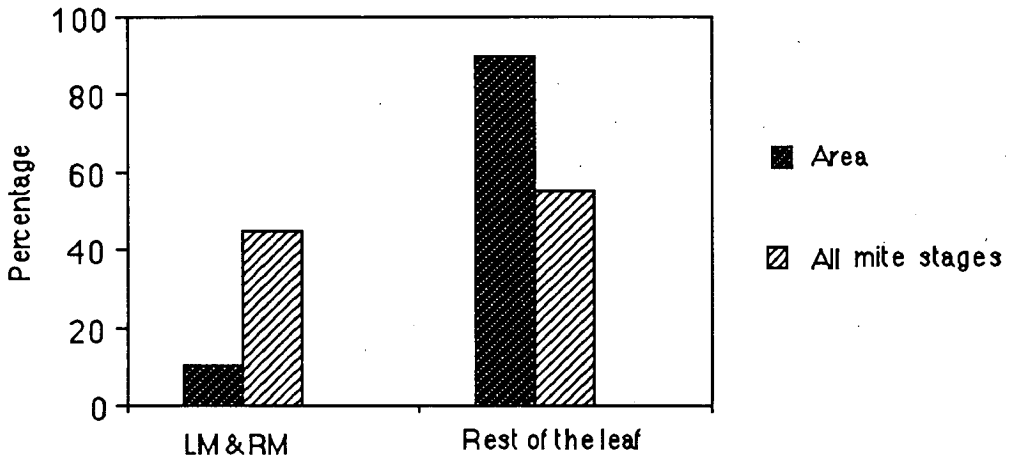
Throughout this study, mites were seen mainly on the lower surface of hop leaves. There were no mites found on the upper surface except when the lower surface area was occupied fully by mites.

4.3.4.1. The distribution of mites

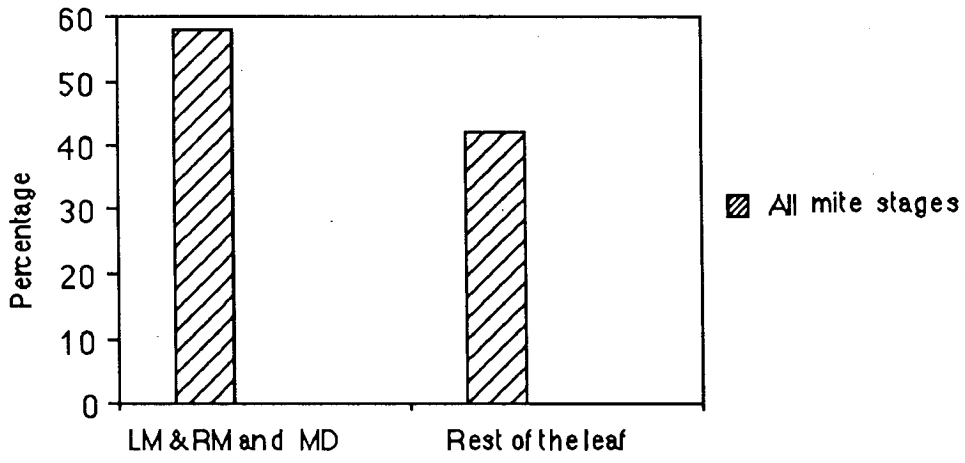
It was found that on a single leaf, mites were mainly distributed in the middle region of the leaf. On this middle region (LM + RM, approximately the size of the fictitious triangle and having only an average of 10% of the surface area of a whole leaf), an average of some 38% of the total adult female mites and 45% of all stages of mites were found. With the addition of the middle distal part (MD, the distal part of the middle leaflet), the average number of all stages of mites increased to nearly 58%, whereas the surface area of these parts were less than half the total leaf area(Fig. 4.24.). The relationship between these percentages and the number of all stages of mites on leaves, as shown in Fig. 4.25., clearly indicated that a relatively high percentage of all mites on a leaf were aggregated on a fairly small area of leaf irrespective of the mite density on the leaf, i.e., it was a preferred region. The two constants in the equations in Fig. 4.25., 47 for the middle region (LM + RM) and 61 for that middle plus the middle distal region (LM +RM +MD), was aproximately the same as the proportions of the populations given above.

Fig. 4.24. Comparison of percentage of mites (all stages or adult females) occurring in the area LM-RM and LM-RM-MD to that on the rest of leaf.

a. LM & RM to the rest of the leaf.



b. LM & RM and MD to the rest of the leaf.



c. Adult females on the fictitious triangle to those on the other area.

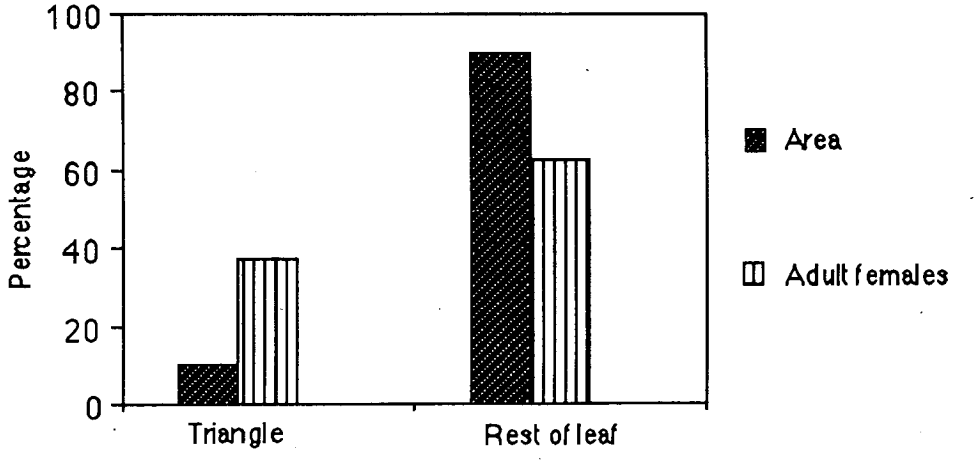
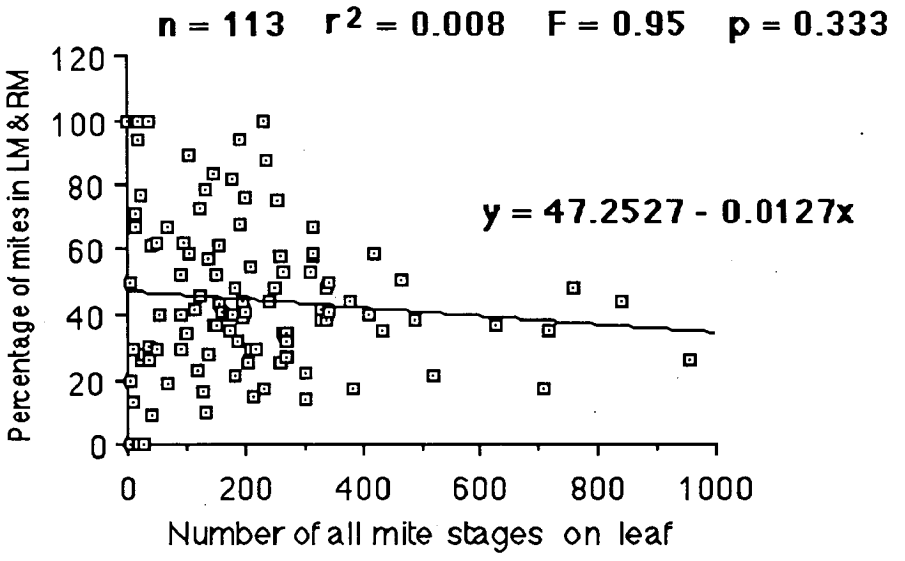
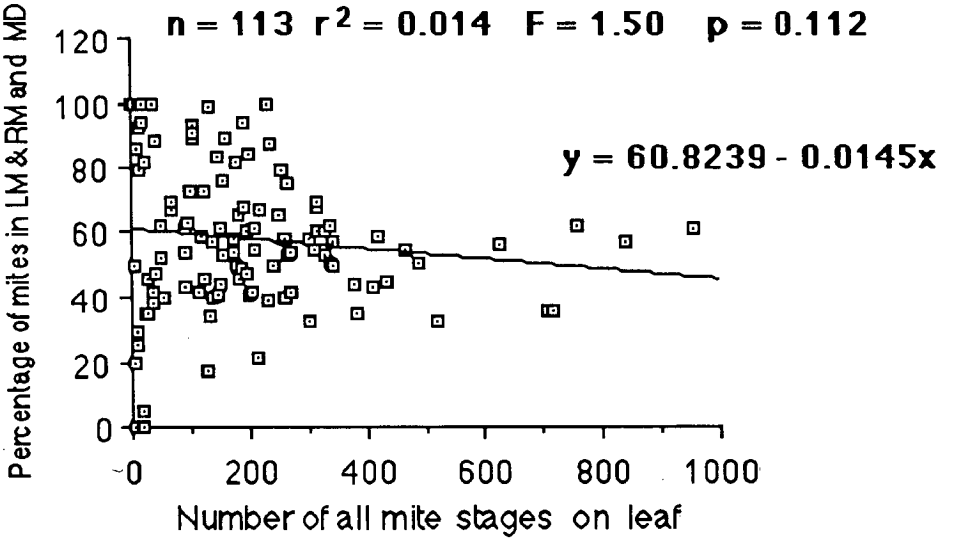


Fig. 4.25. The relationship of numbers of all stages of mites on hop leaf and the percentages of mites in areas LM-RM and LM-RM-MD.

a. for LM & RM.



b. for LM & RM and MD.



4.3.4.2. Estimating mite densities on leaves by the numbers in a defined area

The very significant linear regression relationship between the number of adult females in the fictitious triangle and that on the whole leaf (Fig. 4.26.) demonstrated that the numbers of adult female mites on a leaf can be predicted from the numbers of adult females in that artificially designated triangle, or approximately the middle region of the leaf.

From Fig. 4.27., it can be seen that the numbers of all stages of mites on a leaf can be best predicted from the numbers of adult females on the leaf ($r^2 = 0.72$). The relationship between all stages of mites on a leaf and adult female mites in the triangle was rather weak ($r^2 = 0.62$), although statistically significant.

The prediction of the number of all stages of mites on a leaf can also be made from the number of all stages of mites in the middle part of the leaf ($r^2 = 0.71$), or that in the middle part plus middle distal part ($r^2 = 0.85$), the latter being more reliable (Fig. 4.28.).

Fig. 4.26. Linear regression of numbers of adult female mites (A.) in the fictitious triangles to the numbers of A. on the whole leaves.

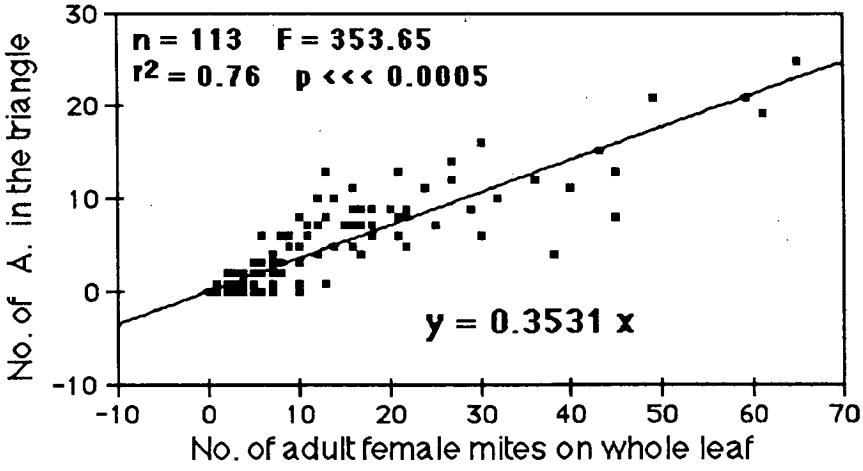
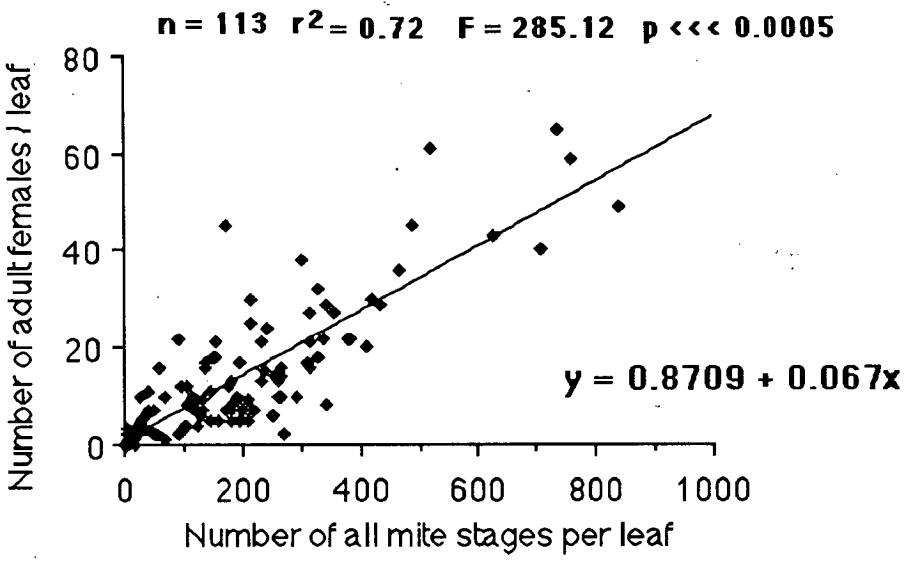


Fig. 4.27. Prediction of the number of all stages of mite on whole leaf from the number of adult female mites on the leaf.

a. from the number of adult female mites on whole leaf



b. from the number of adult female mites in the triangle

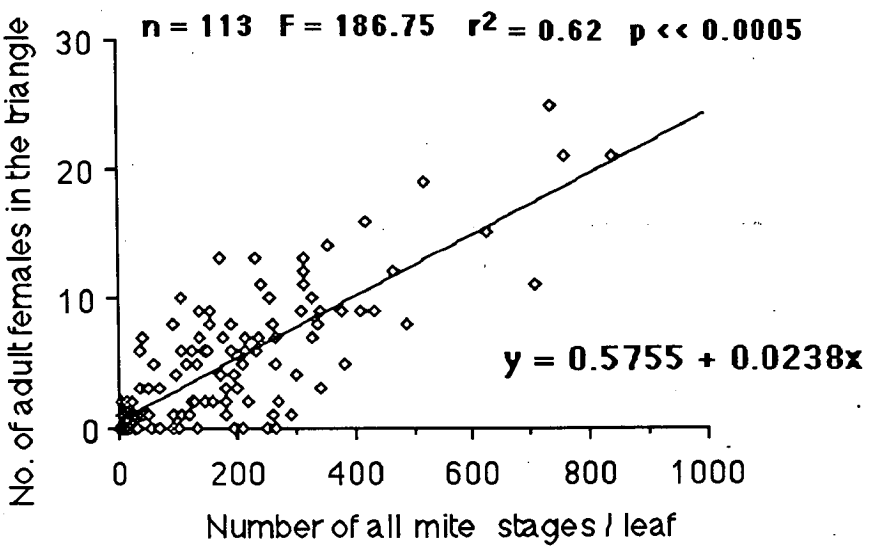
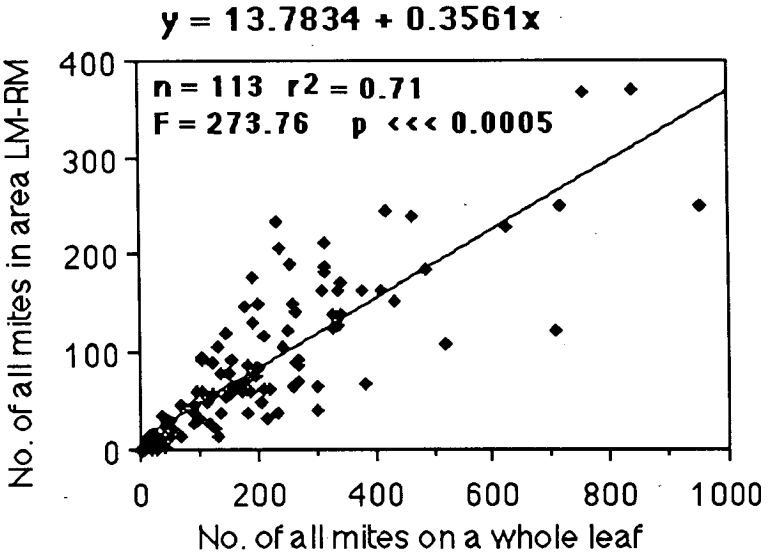
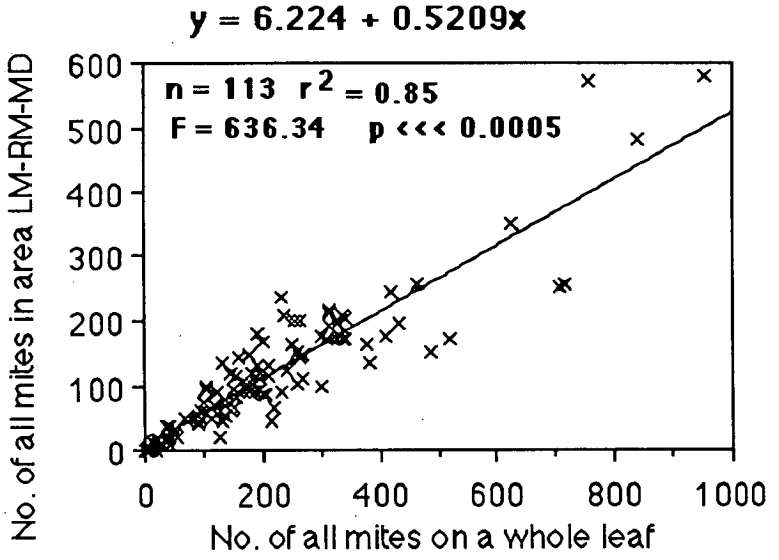


Fig. 4.28. The relationship between the number of all stages of mites on whole leaf and that in certain regions of the leaf.

a. Linear regression of numbers of all mite stages on whole leaf to those in the area LM-RM (approximately the same size as the fictious triangle).



b. Linear regression of numbers of all mite stages on whole leaves to those in the area LM-RM-MD (larger than the fictious triangle).



4.4. DISCUSSION

4.4.1. The Distribution of Mites on the Counting Disc and on Single Leaves

The distribution of dislodged mites on the counting disc is not only academic, but of practical significance. If the mites were evenly and regularly distributed, then the efficiency of counting could be remarkably improved by counting less sections per disc. There is no doubt about the efficiency of removing mites from leaves by the brushing machine. But it was believed that the distribution of mites on a counting disc was non-uniform (Morgan *et al.* 1955 and Williams 1979). In contrast, the result of the present study showed that, although the number of mites for every section is different, the mites are uniformly distributed between sections within every annulus, within different count tracks, and even on the whole disc, as all the C.D.'s are less than 1 in Table 4.5.. The disagreement probably resulted from different statistical methods. Morgan *et al.* did not appear to have tested the dispersion pattern but only concluded from the fact that (i) there were more mites deposited near the periphery than the center; and (ii) the density of mites from sector to sector varied considerably. Actually, these two facts were also encountered in this study, but further analysis resulted in a completely different conclusion. Williams applied the chi-square test and arrived at the conclusion that the mites were not uniformly distributed in sectors around disc. However, from the data in her thesis (p.48, Table V), it can be seen that the coefficients of dispersion for mites between sectors actually are all less than 1 (all $s^2 << \text{means}$), indicating that the distribution of mites was uniform among sectors around the disc.

The results from different heights (i.e., from different mite densities in this study) revealed that there was hardly any variation in the patterns of the dispersion of mites on the counting disc despite the different mite densities. In fact, it is reasonable that the more mites on a given disc, the more likely that mite distribution would be more regular, or uniform.

From Table 4.5., it is clear that in order to have all C.D.'s smaller than 1 and all C.V.'s as small as possible, a minimum mean of 8 mites (all stages) per section should be present on the counting disc. This will result in a total of 1408 mites (all stages) on whole disc. In other words, the distribution of mites will be uniform on the counting disc if there are at least 1400 mites (all stages) on the disc. Binns (1989) suggested that care should be taken to use the brushing machine to give as uniform a distribution as possible. In order to obtain a mite distribution as uniform as possible on a counting disc, a few leaves, rather than one leaf, should be used (as the case in this study) to increase the numbers of mites on the disc. The fewer mites the sample leaves have, the more leaves should be brushed. If the mite densities are very low there is no need to use the brushing machine for a small leaf sample.

However, although distributed uniformly, the mean number of all stages of mites is not the same for all the 11 annuli. This suggests that no single annulus can be neglected when estimating mites on the counting disc. Nevertheless, the mean number of mites, either of individual stages or of all stages, are all the same for those 4 different counting tracks and this has a most significant value in the practical determination of mite densities, as it proved that any counting track can be used and that counting only one track (11 sections) is adequate for estimating the whole mite population on a disc.

4.4. DISCUSSION

4.4.1. The Distribution of Mites on the Counting Disc and on Single Leaves

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The results from different heights (i.e., from different mite densities in this study) revealed that there was hardly any variation in the patterns of

the dispersion of mites on the counting disc despite the different mite densities. In fact, it is reasonable that the more mites on a given disc, the more likely that mite distribution would be more regular, or uniform.

From Table 4.5., it is clear that in order to have all C.D.'s smaller than 1 and all C.V.'s as small as possible, a minimum mean of 8 mites (all stages) per section should be present on the counting disc. This will result in a total of 1408 mites (all stages) on whole disc. In other words, the distribution of mites will be uniform on the counting disc if there are at least 1400 mites (all stages) on the disc. Binns (1989) suggested that care should be taken to use the brushing machine to give as uniform a distribution as possible. In order to obtain a mite distribution as uniform as possible on a counting disc, a few leaves, rather than one leaf, should be used (as the case in this study) to increase the numbers of mites on the disc. The fewer mites the sample leaves have, the more leaves should be brushed. If the mite densities are very low there is no need to use the brushing machine for a small leaf sample.

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Gupta *et al.* (1975) showed that *T. neocaledonicus* was evenly distributed on the lower surface of eggplant leaves. The fact that TSSM is only found on the lower surface of hop leaves and on certain parts of the

lower surface is also of practical significance, as the level of infestation can be easily and quickly decided by examining only the middle part around the main vein, with 70% of the variation in the model being explained.

4.4.2. Estimating Mite Densities in Simpler Ways

From the results of this study, it is obvious that the estimation of mite densities in hops can be facilitated greatly in a number of ways.

As the counting of mites is a tedious and time-consuming task, many workers tend to count only a small fraction of a sample. Cone (1968 and 1985) estimated the mite populations by counting one-tenth of the mites on each plate when studying TSSM in hops. In studying *Mononychellus tanajoa* (Bonder) on cassava, Braun *et al.* (1989) counted 4 of the 12 sectors of the glass plates and corrected these counts (all mobile stages) by multiplication by 3.57, the inverse of the slope ($r^2 = 0.97$; slope = 0.28) of the regression line relating them to direct mite counts (mobile stages) made with a stereomicroscope before brushing. The "modified counting method" not only enables the investigator to census only black sections and therefore avoid the unfavourable background of the white sections, but also gives a better representation of the distribution of mites on the plate in contrast to those occurring on a one-line sector. There were no intercepts fitted to the models of the numbers of mites from discs and the actual numbers of mites, for if the whole population is zero, then the number of mites on the disc must be zero as well. Models in Figs.4.18., 4.19., and 4.20. were used later throughout this study to estimate the populations of eggs, larvae plus nymphs, and adult female mites, respectively. As it has been demonstrated that the numbers of mites are significantly different between annuli, a minimum of one section as the representation of each annulus must be censused to estimate the mites density on a plate. This method minimized

the counting to one-sixteenth of the area of a counting plate without any loss of accuracy and reliability. Therefore, mite density can be estimated much more rapidly by applying the "modified counting method", which is less tedious and time-consuming and provides prompt information to the pest management decision.

Carey (1982) showed that a stable age distribution (SAD) for TSSM was roughly 66% eggs, 26% immatures, and 8% adults and that natural mite populations are often quite close to this SAD. This made it theoretically possible to predict the mite density from any mite stage. In agricultural acarology, the adult female is the stage preferred for counting because the female is the largest stage and the only stage seen with naked eye, and its proportion in the total population is generally small. Marcano-Brito (1980) demonstrated that the density of three tetranychid mites on cotton could be estimated by the linear regression of the total population per leaf to the number of adult females per leaf. Jones and Parrella (1984), Mollet and Sevacherian (1984), and Perring *et al.* (1987) all obtained significant linear regressions for *Panonychus citri* on lemons, *T. cinnabarinus* on cotton, and *T. urticae* on cantoloupe, respectively. Jones and Parrella (1984) did not fit an intercept in their regression, as it was considered that if the total population of a sample is zero, then the number of females must also be zero. Therefore, their regression line was forced through the origin. However, on the other hand, if the number of adult females is zero, the total population is not necessarily zero. This is because (i) according to SAD, the number of adult females is usually very small and a large proportion of a population is other mite stages; (ii) the teneral or even the deutonymphal females are often found to migrate from their family territory to new, unoccupied leaves; and (iii) adult females are a most prominent and fairly

active stage, it is very likely that these females simply disappeared during the sample handling procedures. Therefore an intercept was fitted in the equation for estimating the total population from the number of adult female mites in this study.

Counting the adult female mites on leaves with the naked eye in the field seems to be comparatively the easiest method. Therefore, for small samples, the ideal procedure would be: (1) count adult females in field; (2) obtain the actual number of adult females on leaf from the model in Fig. 4.23 ; and (3) estimate the whole population from the equation in Fig. 4.27. If the sample is relatively large or is difficult to count due to factors such as unexpected unfavourable weather, very high levels of infestation, limited time or other reasons, then it would be easier to handle the sample with the brushing machine and counting disk. The population can be best estimated with the models in Figs. 4.18.-22.. Otherwise the population density can be simply estimated by counting either the number of adult females or the number of all stages of mites in certain parts of the leaves under a binocular microscope, then applying those models given in Figs. 4.26.-28..

4.4.3. Determining the Number of Sections to be Counted on Counting Disc

According to Snedecor (1946), sample size can be estimated by the formula: $n = (t^2) * (C.V.^2) / E^2$,

Where n = number of sample (sections to be counted),

t = Student's t for for desired confidence level (1.65 for 90%; 1.96 for 95%),

C.V. = coefficient of variation,

E = one half the confidence interval desired, usually 10%.

In the formula, *t* and E are relatively fixed, the only variable is C.V., and n varies with C.V. exponentially. From Fig. 4.13., it can be seen that when the mean number of all stages of mites per section is more than 50, the C.V. becomes almost constant, therefore, the number of sections to be counted becomes almost constant as well. For example, using the C.V. from Table 4.5., it is found that n = 3.11 for the height division of 270-360 cm (mean mites per section = 68.98), and n= 3.84 for 360-500 cm (mean mites per section = 53.50). Obviously, when the mean is below 15, the C.V. increases dramatically, and this in turn will increase n significantly. Thus, if the mean number of mites per section is low, then the number of sections to be counted would be high, and *vice versa*. Clearly, it can be easily found that if the number of mites per section is low, then the time required to count a single section will be less than that if the number of mites per section is higher, but the number of the sections to be counted is increased. Therefore, the optimal counting method should provide the best estimates and be less time consuming.

From Williams (1979), in order to count only one sector on a counting disc, the mean mite numbers per sector should be no less than 256. This represents a total of 4096 mites on the disc. However, from the present study, when using the modified counting methods, in order to count 11 sections in one count track which is of equivalent area to one sector, it only requires a mite density of 1900* on a disc, approximately 11 mites (all stages) per section, which is higher than the minimum requirement for a uniform distribution of all stages of mites on a counting disc.

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* calculated as follows:

In formula $n = (t^2) * (C.V.^2) / E^2$,

if n = 11 for the number of sections of one count track, t = 1.96 for 95% confidence level, E = 10 as the required level of accuracy, C.V. would be 16.92. Then from the equation in Fig. 4.13., $y = 90.563\ x^{-0.705}$, the mean mites (all stages) per section is approximately 11.

CHAPTER FIVE

THE CONTROL OF TSSM ON HOPS

CHAPTER 5 THE CONTROL OF TSSM IN HOPS

5.1. INTRODUCTION

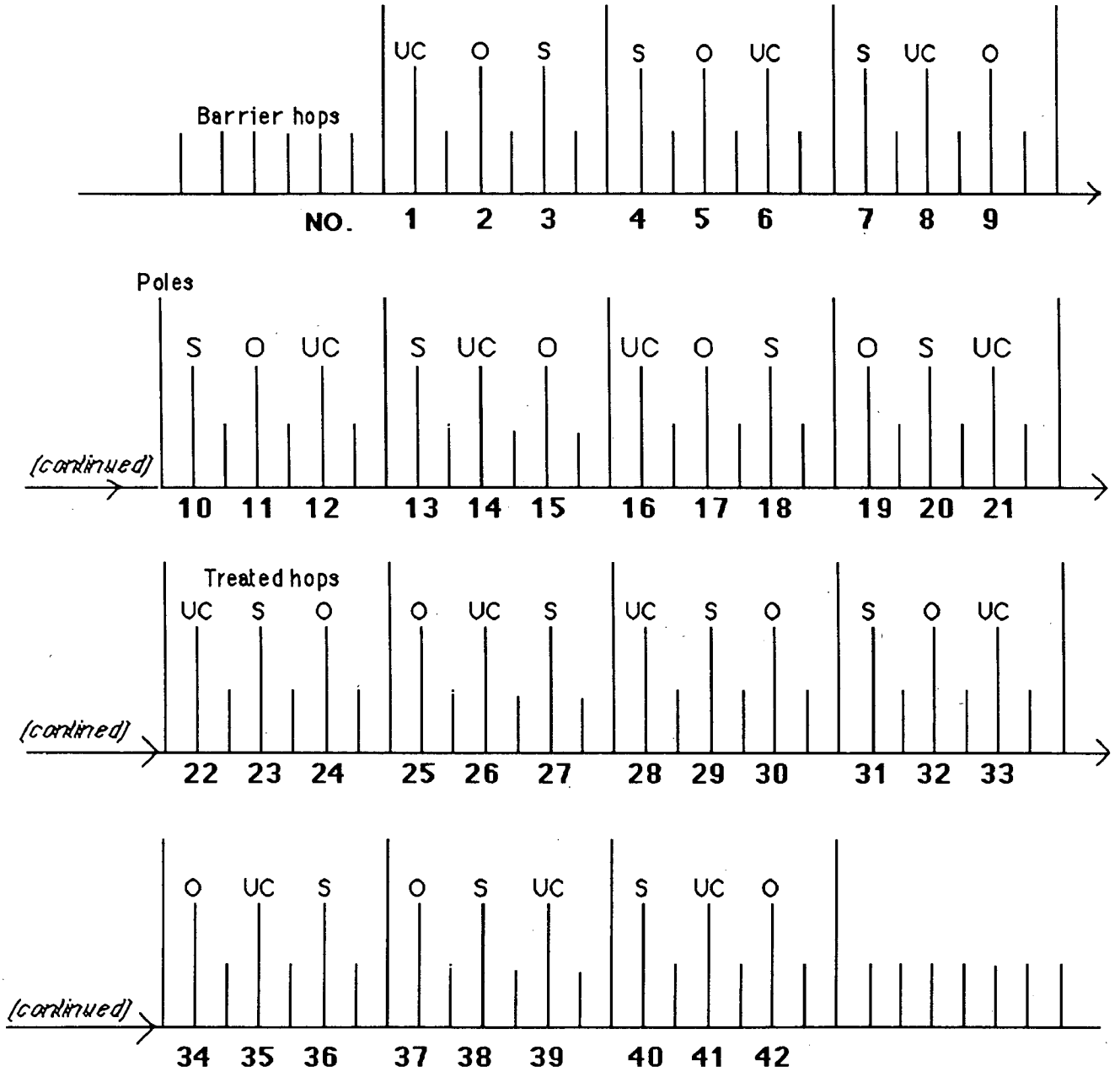
One of the main aims of IPM is to diminish or, ideally, eliminate the application of organic synthetic pesticides to avoid the increasing serious consequences of excessive usage of these chemicals. An ideal chemical would be one that kills the pest effectively without causing much damage to the natural enemies of the pest and the environment in general. Natural enemies play very important roles in maintaining an equilibrium between the prey and the predator and thereby checking pest population outbreaks. To test the efficiency and applicability of lime-sulphur and summer (white)-oil on TSSM in hops in Tasmania, various experiments were designed and carried out mainly in the growing season of 1987-88.

The main purpose of the work reported in this chapter was to evaluate the effects of lime-sulphur, summer-oil and a predatory mite *P. persimilis* on TSSM populations in hops and the potential of cultural control of the pest.

5.2. MATERIALS AND METHODS

The experimental plot was established in the middle of a commercial "Pride of Ringwood" hop yard, some 4 ha. in size at Huonville, in early September, 1987. It consisted of one single hop row with 120 hop plants in an East-West direction, with one hop row on each side as barrier. It was approximately 0.12 ha. in size. Forty two hop plants in the middle row were chosen as study plants in this experiment and designated from No. 1 to No. 42, with one hop hill between every two adjacent study plants (Illustration 5.1.).

Illustration 5. 1. The location of hop plants for receiving Lime-sulphur (S) and Summer-oil (O) sprays, and untreated controls (UC) in the experimental plot at Huonville for the year of 1987-1988*.



*: This plot was in fact one hop row, consisting of 78 hop plants, with one hop row on each side as barrier. Later, some modifications of some treatments were applied to this original setting according to the experimental design.

Whenever a spray was applied to the surrounding commercial crop, it was ensured that plants in the experiment plot did not receive any of these sprays. Otherwise the test plants were treated the same as all other plants with respect to cultural activities. Thus, the TSSM on the study plants received minimum disturbance from commercial sprays so that the mite could be studied under approximately undisturbed and natural conditions.

When it was necessary, a 3.5-metre-high ladder was used to collect leaves from the 4 upper height intervals.

Estimating the absolute density of the mites on the basis of per unit area was considered to be a rather large task, for it was related to not only the area and growth of individual hop leaves, but also the number and increase in hop leaves. Thus, all efforts were concentrated on comparing the differences among and between treatments rather than monitoring actual population dynamics.

5.2.1. The Application of Lime-sulphur and Summer-oil

Initially, the 42 plants were divided randomly into three groups with an equal number of hop plants for use as: (1) untreated controls, (2) receiving applications of lime-sulphur and (3) those receiving applications of summer-oil (Illustration 5.1.).

Lane's Harola Lime-sulphur, (200g/L sulphur as polysulphide sulphur) was diluted to a recommended dilution of 10 ml/L (lime-sulphur/water), or 2 g (sulphur)/L(solution). Hortico^{TM} White-oil (880 ml/L petroleum oil) was diluted to a recommended dilution of 10 ml/L (white-oil/water), or 8.8 ml (petroleum oil)/L (solution). A 15 L capacity Tris knapsack sprayer (Birchmeir) was employed to apply the two

materials to hops for the first two sprays. The third spray was conducted with a Rega hand compressor sprayer (with 3 m extension).

When sprays were applied, efforts were taken to ensure that all the leaves, especially the underside surfaces, were wetted by the sprays.

5.2.1.1. The first spray

On November 6, 1987, plants were sprayed as designated in Illus. 5.1., that is , plant no's. 2, 5, 9, 11, 15, 17, 19, 24, 25, 30, 32, 34, 37, and 42 received summer-oil at a rate of 1 L (solution)/plant; plant no's. 3, 4, 7, 10, 13, 18, 20, 23, 27, 29, 31, 36, 38, and 40 received lime-sulphur at a rate of 1 L (solution)/plant; plant no's. 1, 6, 8, 12, 14, 16, 21, 22, 26, 28, 33, 35, 39, and 41 were left unsprayed as untreated controls.

Before spraying, on November 5, 1987, leaves were sampled from the low part (height interval 0-0.9 m)* of all hop hills at 5 leaves/hill. Samples from each hill were placed in a plastic bag and brought back to the laboratory for examination. Numbers of eggs, larvae plus nymphs, and adult females were counted separately under a binocular microscope at a magnification of 8- or 15-fold. The number of adult female mites in other height intervals were counted by the naked eye in the field without detaching the hop leaves from the vines.**

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*: The early stages of hop plants have a very limited numbers of leaves on their vines, therefore, no leaves were removed from the vines attached to the strings. All leaf samples before January 17, 1987 were collected from the base clumps so as not to interfere with the normal plant growth .

**: See Fig. 4.1. for details of the height dividing.

After spraying, all three treatments were sampled on November 12, 18, 26, and December 2, 1987. Sampling was as described above. The numbers of mites were averaged for the 14 plants to obtain the mean number of mites/leaf in order to compare the different treatments.

5.2.1.2. The second spray

A second spray was applied, when it became necessary, on December 2, 1987. Five of those plants which received the first spray were treated with each test material. Plant no's. 2, 17, 19, 30 and 32 received summer-oil at a rate of 1 L (solution)/plant (at this stage, the base clumps had been already buried in one of the cultivation activities) and no's. 7, 10, 13, 23 and 31 received lime-sulphur at a rate of 1 L (solution)/plant.

A pre-spray sampling for all the experimental plants was made on December 2, 1987. On December 21, 17 days after spraying, leaf samples were collected again for the plants receiving the second spray as well as those not sprayed.

5.2.1.3. The third spray

On January 25, 1988, a third spray was applied. Plant no's. 2, 5, 9, 11, 17, 19, 24, 30, 32 and 34 were sprayed with summer-oil at a rate of 1 L (solution)/plant. Plant no's. 3, 4, 7, 10, 13, 18, 23, 27, 31 and 38 received lime-sulphur at a rate of 1 L (solution)/plant. Spray was applied with a Rega hand-compressor sprayer.

All the experimental plants were sampled on January 17, 1988, at one leaf/string/height interval/plant, to give three leaves for every height interval, and a total of 15 leaves for each hop plant. In the laboratory, leaf samples from each height interval for each treatment were run through

the mite-brushing-machine as one lot and the mites from these leaves were collected onto one disc. Mite densities were estimated by applying the "modified counting method", which included: 1) counting the mites along the counting track of 8-2; 2) multiplying the numbers obtained from 1) by 16; and 3) estimating the densities of mites by applying the models in Figs. 4.18., 19., and 20..

A post-spray sampling was carried out to evaluate the effects of the sprays, 20 days after spraying, on February 14, 1988. Plants were sampled in the same way as the pre-spray sampling except that there were no leaves to be sampled from the height interval 0-0.9 m, as these leaves had been consumed by sheep as part of the cultural activities. The same procedure of estimating mite densities was employed.

The populations of adult female mites on commercially sprayed hops were monitored throughout the two seasons, 1987-1988 and 1988-1989.

5.2.2. The Release of the Predatory Mite *Phytoseiulus persimilis* (Athias-Henriot)

Predators were imported from Biocontrol Ltd. in Queensland and released onto hop plants immediately after arrival. The predators were released on hop plant no's. 1, 16, 21, 22, 26, 28 and 33, i.e., half of the untreated controls, on December 10, 1987. Three to four bean leaves, on which the predator was cultured and transported, were fixed with a pin on the upperside of hop leaves approximately 0.4-0.9 m from the ground. The release rate was approximately 40 mobile predators per hop plant.

On December 2, 1987, leaf sampling was carried out for all the plants. All the sampling and counting procedures were the same as described in 5.2.1.1.. The numbers of mites from half (seven plants) of the untreated

controls, i.e., plant no's. 6, 8, 12, 14, 35, 39, and 41, and the other half (seven plants), i. e., plant no's. 1, 16, 21, 22, 26, 28, and 33 (which would receive the release of *Phytoseiulus persimilis* later) were averaged respectively in order to compare the effect of different treatments.

As the experiment was on a small scale, only seven plants received the predator, and sampling did not take place until January 17, 1988, thirty-eight days later, in order not to disturb any build up of the predator population.

On January 17, 1988, as mentioned above in 5.2.1.3., all the experimental plants were sampled. Numbers of mites from the seven untreated plants and the seven predator-release plants were estimated again separately in the same way as described in 5.2.1.3., and then compared.

5.2.3. Monitoring Plant Growth and the Dispersal of Mites on Hop Plants

Efforts were taken in order to understand the relationship between plant growth and the vertical movement of mites on hop plants. The sampling schedules and procedures are given in Table 5.1.. The operations included on every sampling date were: (1) measuring actual hop plant growth (the length of vines above ground); (2) recording the height level the mites have reached; and (3) counting the number of adult females in each height interval from 0-0.9 m up to the top of various growth stages of the hop plants.

5.2.4. Aspects of Cultural Control of TSSM on Hops

During the two-year-period working on TSSM on hops, it was observed

that some cultural activities had some potential to control TSSM. Therefore efforts were made to investigate this potentiality mainly in the growing season of 1988-89.

Table 5.1. Sampling schedule and procedures for monitoring hop plant growth and TSSM dispersal on hops.

	No. of leaves per height interval per plant				
Sampling Date	Untreated Control	Sulphur 2 sprays	Sulphur 3 sprays	Oil 2 sprays	Oil 3 sprays
5/11/87	5	5	5	5	5
18/11	5	5	5	5	5
2/12	5	5	5	5	5
21/12	5	5	5	5	5
1/1/88	3	3	3	-	-
7/1/	-	-	-	3	3
17/1	3	3	3	3	3
14/2	3	3	3	3	3

5.2.4.1. The effect of early ploughing

It had been observed that in late winter and early spring, overwintered adult female mites moved to a weed, California thistle (*Cirsium arvense* (L.) Scop.), before the shooting of hops (see 3.3.1.2. for details), so in 1988, around September 10, three hop fields (designated as field 1, 2, 3 respectively for convenience) were ploughed instead of the previous autumn or early winter which was the traditional time for ploughing There was one field (designated as field 4) left without ploughing as control. After ploughing, hop leaves were sampled in these four hop fields on November 10, November 20, and December 8, 1988. Various numbers of

leaves collected from fields at these times are given in Table 5.2..

Table 5.2. The numbers of hop leaves collected from hop fields.

Date	Ploughed fields			Unploughed field
	1	2	3	4
Nov. 10	100	107	104	97
Nov. 20	161	156	133	121
Dec. 8	80	96	111	116

Following sampling, the numbers of leaves infested or non-infested by TSSM were recorded for the four grounds and the percentages of infested or non-infested leaves in the total number of leaves from each field were calculated. The numbers of different mite stages, divided into three groups of eggs, larvae plus nymphs, and adult female mites, were censused under a stero-microscope (10-fold) and recorded separately, then compared on the basis of numbers of mites per leaf.

5.2.4.2. The influence of temperature and humidity on the development of TSSM populations

"Press-Button" maximum and minimum thermometers, located around the base of hops at a height of 50 cm above the ground, were used to monitor the weekly temparatures in hop fields from early spring to late summer for the years of 1987-88, and 1988-89.

General rainfall records in the district in the two years were obtained

from the Bureau of Meteorology. When the crop was irrigated by a sprinkler irrigation system in the middle of December, 1988, the relative humidity inside the hop field was monitored with a Bacharach psychrometer.

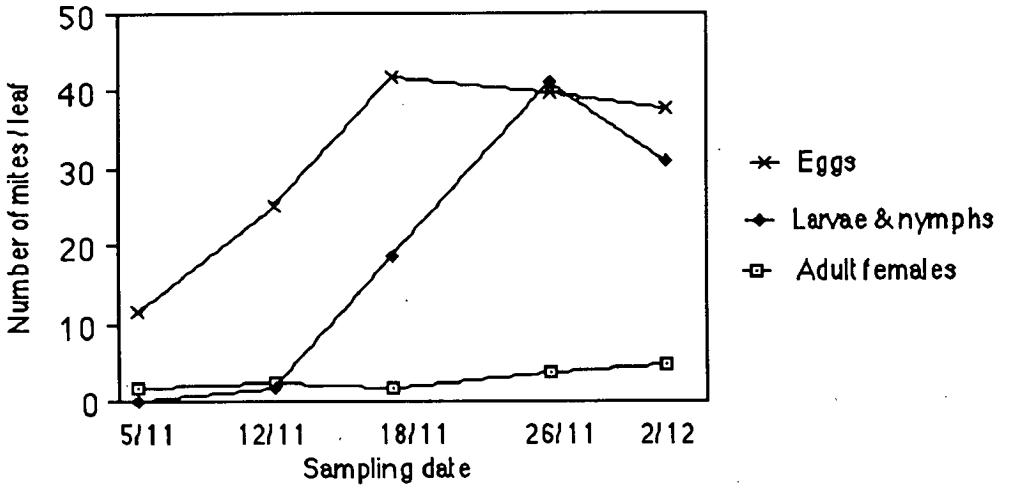
5.3. RESULTS AND OBSERVATIONS

5.3.1. The Effect of Lime-sulphur and Summer-oil Sprays

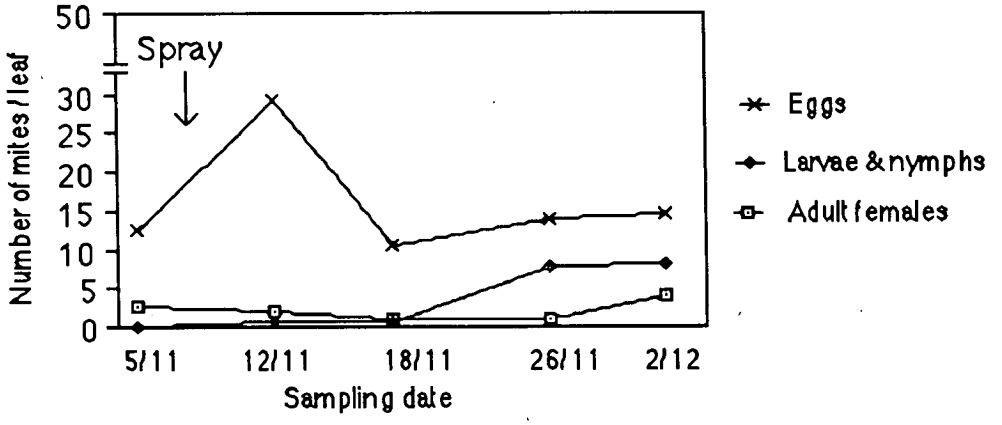
Both materials gave good control over TSSM. The results of the first spray are summarized in Fig.5.1.. From Fig.5.1.a., it is clear that for the untreated control the numbers of eggs increased steadily until November 18, then became constant for the next two weeks; the numbers of larvae and nymphs went up steadily until November 26, then slightly decreased in the following week; while the numbers of adult females steadily increased up to December 12. The reason for the decrease in the number of eggs, larvae & nymphs was probably due to the upward movement of teneral female mites (see later 5.3.3.). For plants sprayed with lime-sulphur, the numbers of larvae & nymphs, and adult females were suppressed and did not increase for the next two weeks; however the numbers of eggs did not fall until one week after the spray. For plants sprayed with summer-oil, the numbers of eggs, larvae plus nymphs, and adult females decreased immediately after spraying, but commenced to increase two weeks later. Fig. 5.2. compares the effect of the different

Fig. 5.1. TSSM population changes with different treatments (see the footnote in Fig. 5.3.) in the height interval 0-0.9 m.

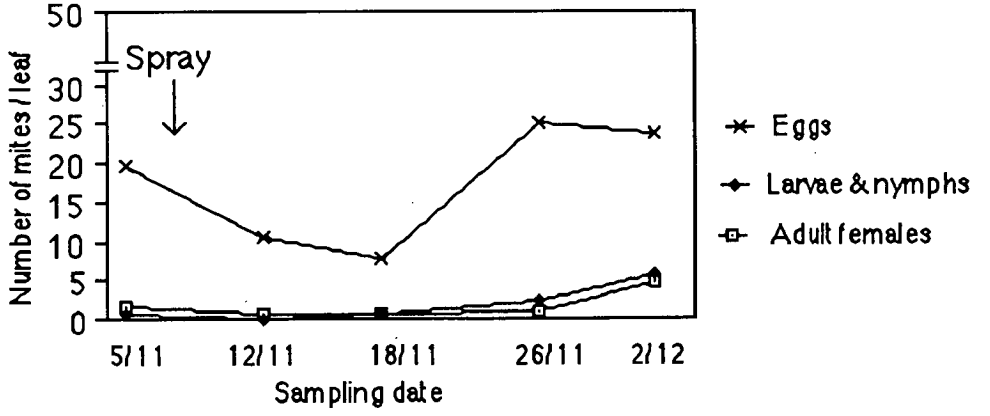
a. for untreated control.



b. for plants receiving lime-sulphur spray on Nov. 6, 1987.



c. for plants receiving summer-oil spray on Nov. 6, 1987.



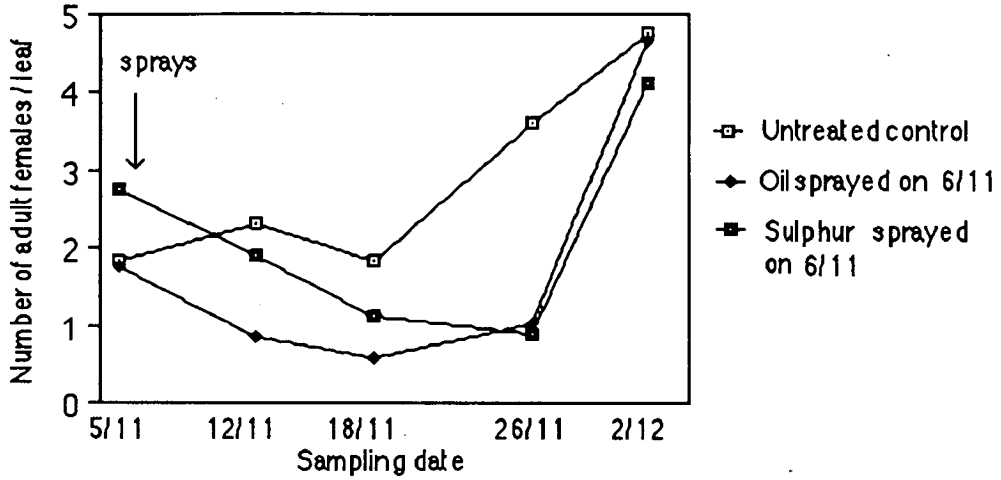
treatments. Obviously, these two materials can, at the recommended concentration, suppress the rapid growth of TSSM populations for a certain period of time. When all stages of mites were considered together for the height interval 0-0.9 m, as shown in Fig. 5.3. and Table 5.2., the suppressing effect of these two materials is apparent. However, mite populations started to increase three weeks after spraying. Comparison between the percentage increase in mite populations on untreated hops of 126 per cent, 280 per cent for those plants treated with lime-sulphur, and 704 per cent for the summer-oil treatment (from November 18 to December 2) showed that populations of adult female mites on treated plants grew faster than those populations on the untreated controls (Fig. 5.3.b.). This suggests that natural regulatory agencies had been removed.

The results of the second spray of lime-sulphur and summer-oil are presented in Fig. 5.4. and Fig. 5.5.. These two sprays did delay the build up of mite populations. The increase in the number of adult female mites, three weeks after spraying, for whole plants was limited to 47.5% and 100% for the plants receiving two sprays, compared with 258% and 791% for the plants received only one spray of lime-sulphur and summer-oil respectively. The growth in untreated control plants was 350 per cent.

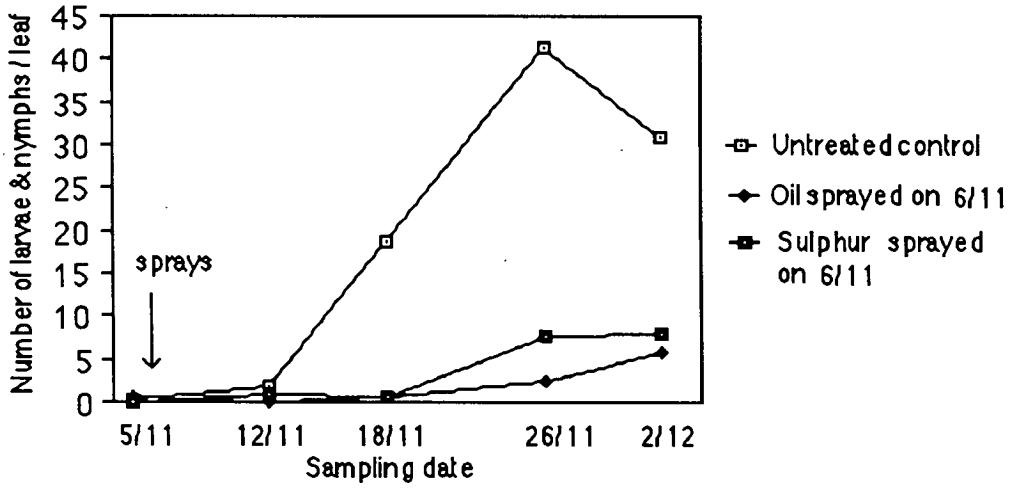
The initial populations of mites for the various treatments are compared in Fig. 5.6. & Fig. 5.7., in order to provide more information for a thorough understanding and comparison of the effect of sprays of lime-sulphur and summer-oil.

Fig. 5.2. The comparison of the effect of the different treatments (see the footnote of Fig. 5.3.) on TSSM populations in the height interval 0-0.9 m.

a. for adult female mites.



b. for larvae and nymphs.



c. for eggs.

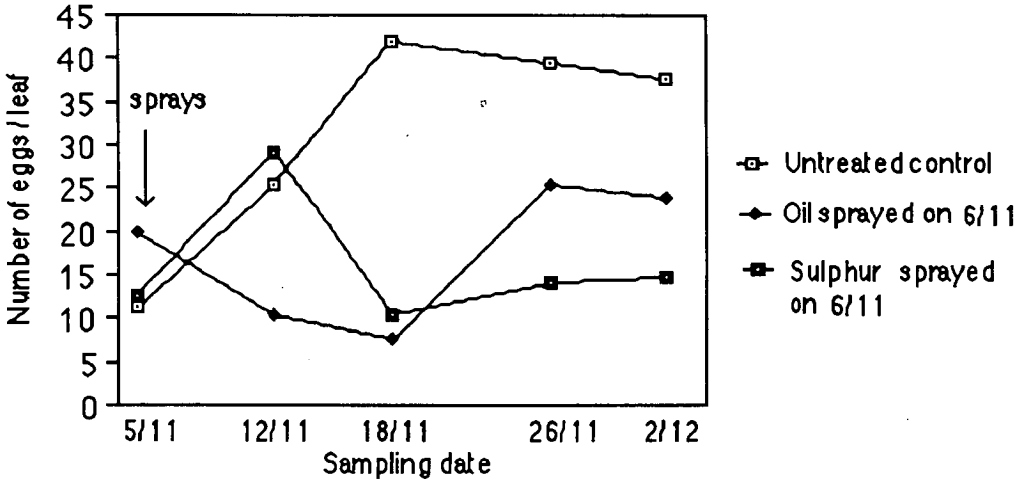


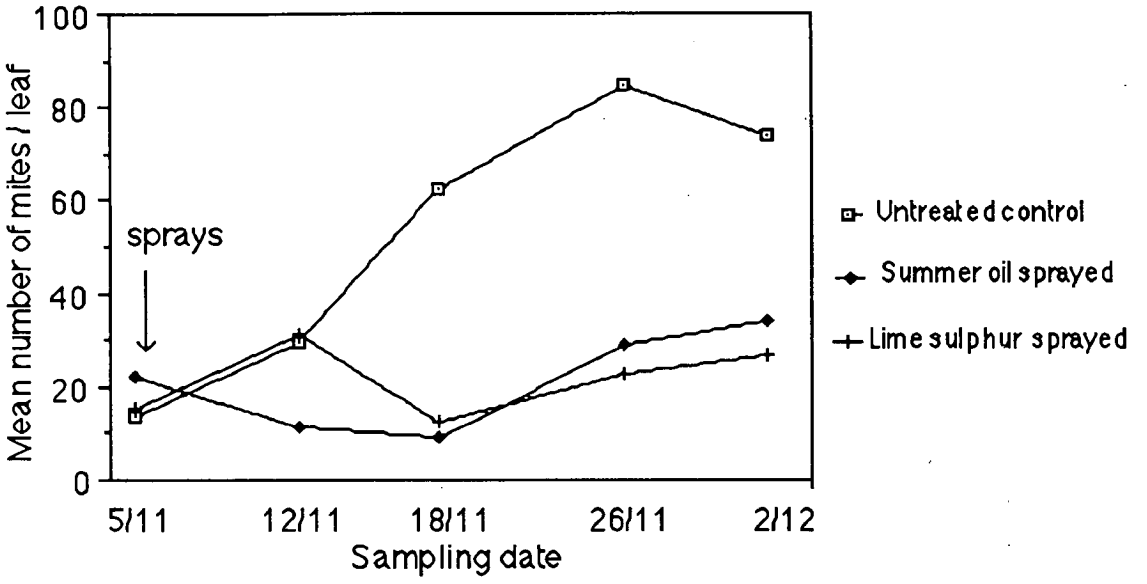
Table 5.3. The percentage changes of TSSM populations (A=adult females; LN=larvae & nymphs and E=eggs), compared with those before spraying, for different treatments, for the height interval of 0-0.9 m.

Sampling		Treatments					
Date		Untreated control		Sulphur sprayed		Oil sprayed	
		No./Leaf	per cent	No./leaf	per cent	No./leaf	per cent
Nov. 5	A	1.85	100%	2.77	100%	1.76	100%
	LN	0.17	100%	0.1	100%	0.57	100%
	E	11.46	100%	12.6	100%	19.76	100%
Nov. 12*	A	2.3	+24%	1.91	-31%	0.84	-52%
	LN	1.76	+935%	0.81	+714%	0.04	-93%
	E	25.27	+121%	29.19	+132%	10.47	-47%
Nov. 18*	A	1.84	-0.5%	1.13	-59%	0.59	-67%
	LN	18.6	+10841%	0.7	+600%	0.67	+18%
	E	41.91	+266%	10.44	-17%	7.73	-61%
Nov. 26*	A	3.6	+95%	0.9	-68%	1.03	-42%
	LN	41.2	+24135%	7.74	+7640%	2.41	+323%
	E	39.63	+246%	14.11	+12%	25.3	+28%
Dec. 2*	A	4.77	+158%	4.13	+49%	4.65	+164%
	LN	31.04	+182%	8.09	+7990%	5.77	+912%
	E	37.77	+230%	14.64	+16%	23.83	+21%

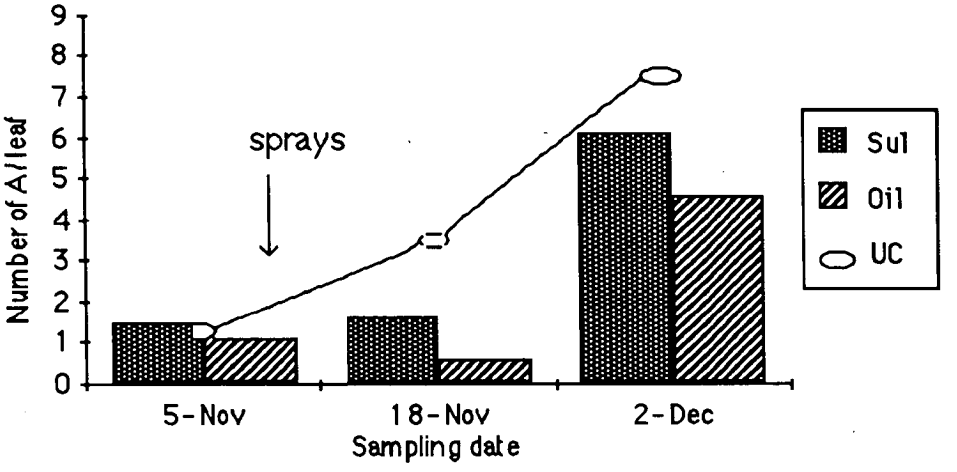
* Percentage changes are all based on the data of November 5, 1987.

Fig. 5.3. The comparison of populations of TSSM between various treatments.

a. for all stages of mites at height interval 0-0.9 m.



b. for adult female mites (A) on whole plants.



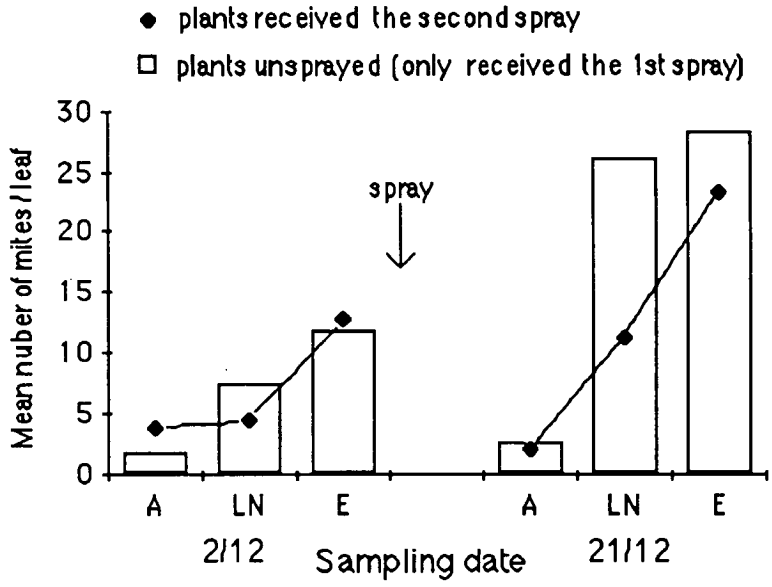
Plants for untreated control (UC): no's. 1, 6, 8, 12, 14, 16, 21, 22, 26, 28, 33, 35, 39 and 41;

Plants for Sumer-oil sprayed (Oil): no's. 2, 5, 9, 11, 15, 17, 19, 24, 25, 30, 32, 34, 37, and 42;

Plants for Lime-sulphur sprayed (sul): no's. 3, 4, 7, 10, 13, 18, 20, 23, 27, 29, 31, 36, 38, and 40.

Fig. 5.4. The effect of a second spray of Lime-sulphur (applied on December 3, 1987) on TSSM populations.

a. comparison of numbers of mites per leaf, within height interval 0-0.9 m, foe adult females (A), larvae plus nymphs (LN), and eggs (E) before and after the spray.



b. comparison of mean numbers of adult females/leaf on whole plants.

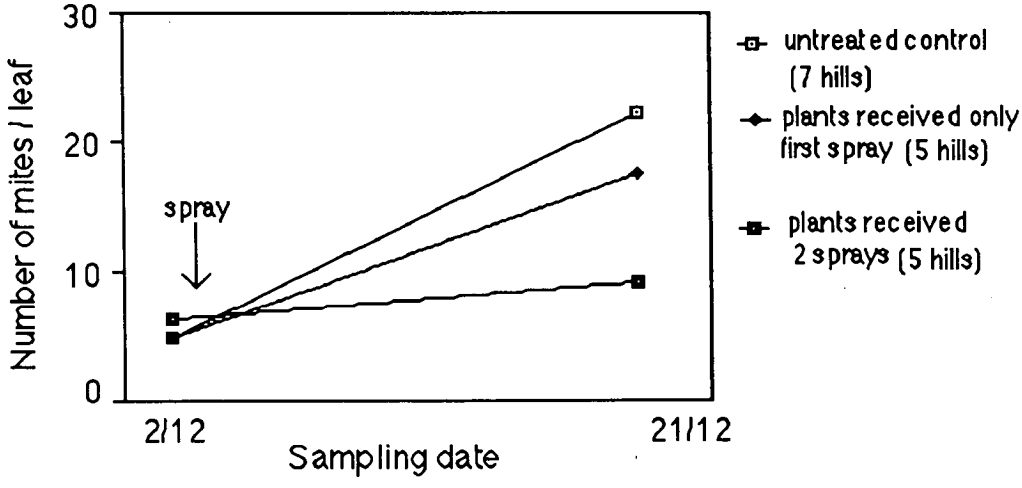
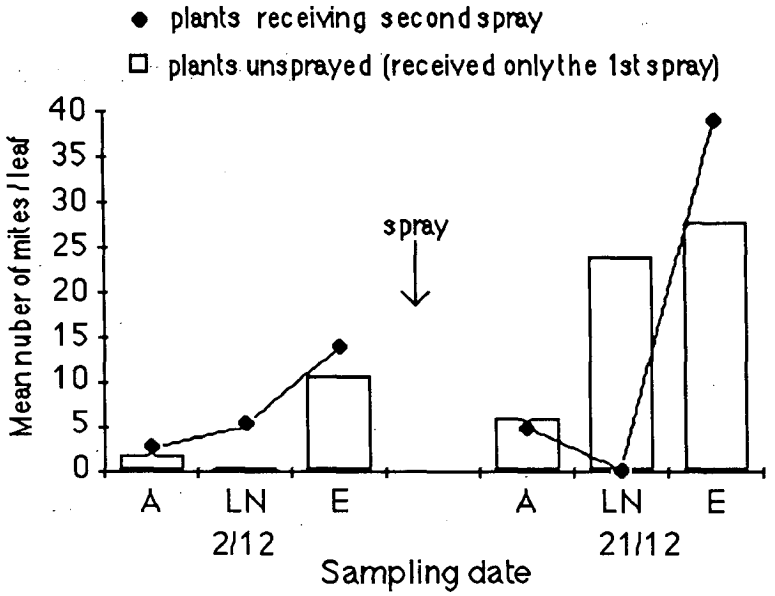
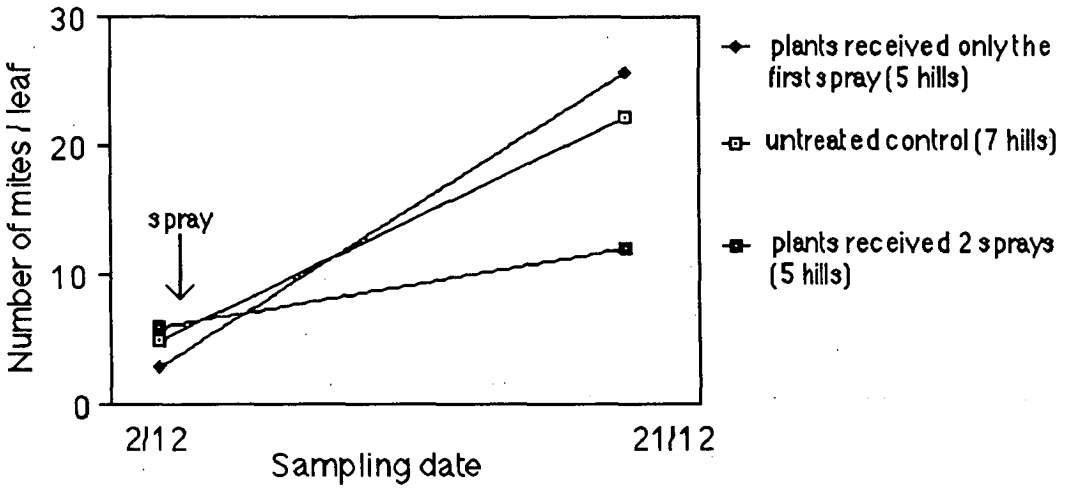


Fig. 5.5. The effect of a second spray of Summer-oil (applied on December 3, 1987) on TSSM populations.

a. comparison of numbers of mites per leaf, within height interval 0-0.9 m, foe adult females (A), larvae plus nymphs (LN), and eggs (E) before and after the spray.



b. comparison of mean numbers of adult females/leaf on whole plants.

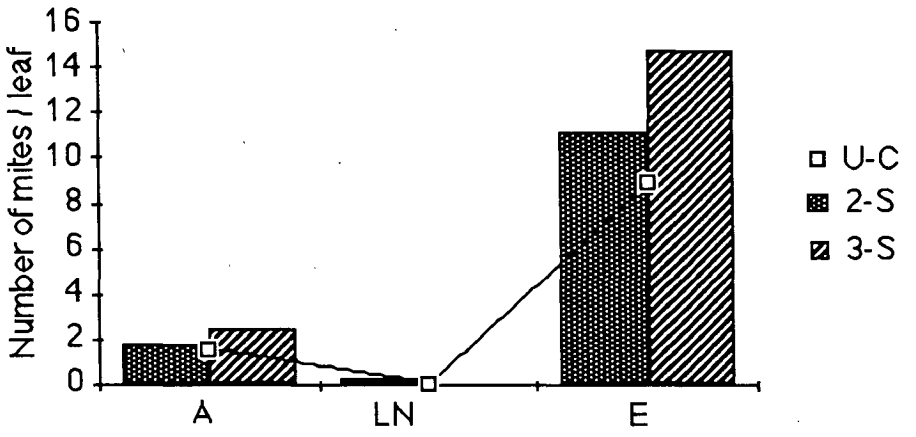


The effect of the third spray of both lime-sulphur and summer-oil were most satisfactorily investigated. As the plants had enough foliage at that time, both pre- and post-spray sampling were conducted on such a scale as to obtain information on the population changes of mites in different life stages, in all height intervals, for the different treatments. The results of the third spray are given in Fig. 5.8. and Fig. 5.9.. The two materials demonstrated again miticidal activity by hindering the population growth of TSSM. However, there appeared exceptional high populations at the height 3.6-5.0 m on the plants receiving three application of lime-sulphur. This was caused probably by the inefficiency of the spraying in covering all the leaves at that height interval when the canopies of hop plants were so dense, or by the remove of unseen natural regulatory agencies. When the numbers of mites were averaged between all height intervals, as shown in Fig. 5.10., the effect and the difference of these two materials became more apparent. In fact, from January 17 to February 14, the mite populations on whole plants decreased slightly for the untreated control, with a 43.4% increase for adult female mites, 12.5% decrease for larvae and nymphs and 7.1% decrease for eggs. These changes probably resulted from unfavourable climatic conditions. In contrast, the decrease in mites populations were 21.3% and 6.8% for adult female mites, 27.3% and 15.27% for larvae and nymphs, 49.8% and 25.7% for eggs, for plants receiving two and three sprays of lime-sulphur respectively; and 29.6% and 63.2% for adult female mites, 67.5% and 82.1% for larvae and nymphs, 35.0% and 62.5% for eggs, for plants receiving two and three sprays of summer-oil respectively.

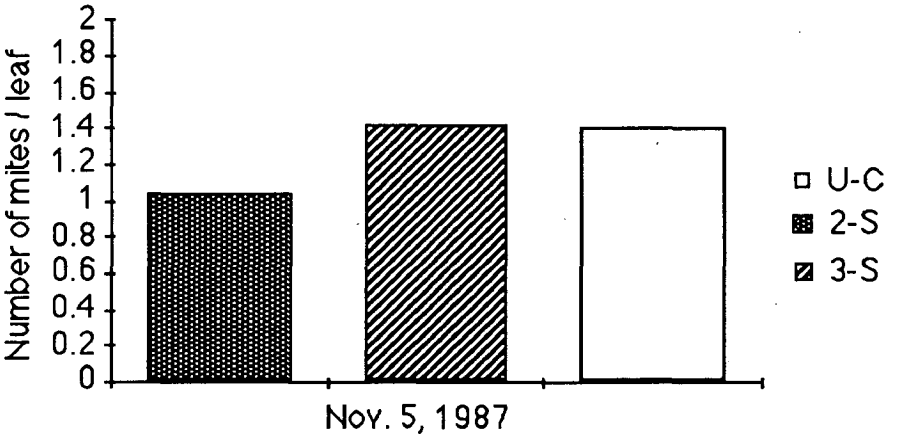
It was observed that both materials appeared to be more detrimental to eggs in particular, nymphal quiescent stages, and displayed little phytotoxicity to sprayed plants.

Fig. 5.6. Comparison of the initial TSSM population size, sampled on November 5, 1987, for treatments.

a. for adult females (A), larvae plus nymphs (LN), and eggs (E) in the height interval 0-0.9 m.



b. for adult female mites on whole plants.

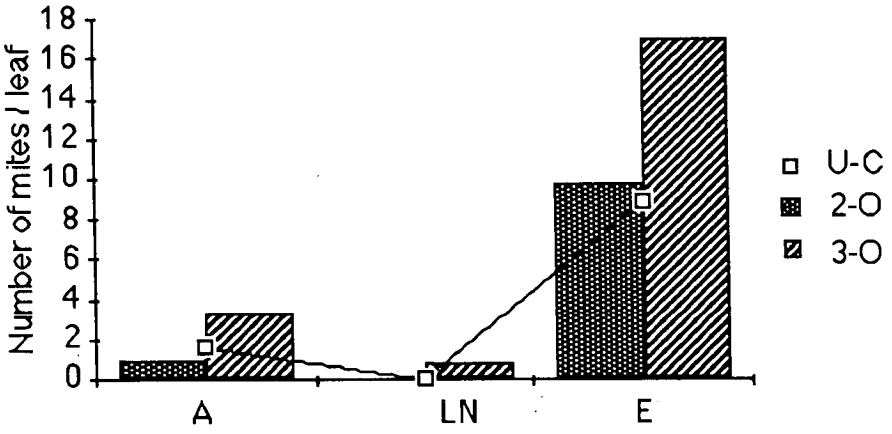


Note:

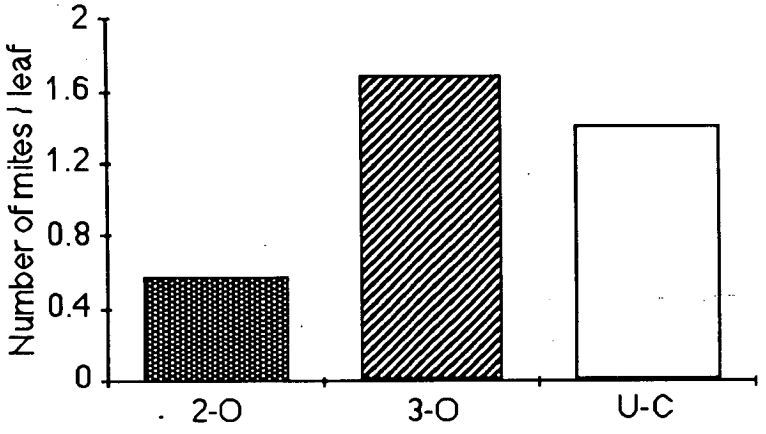
U-C = untreated control, plants no's. 6, 8, 12, 14, 35, 39, and 41;
2-S = plants receiving two sprays of Lime-sulphur, no's. 3, 4, 18, 27, & 38;
3-S = plants receiving three sprays of Lime-sulphur, no's. 7, 10, 13, 23, and 31.

Fig. 5.7. Comparison of the initial TSSM population size, sampled on November 5, 1987, for treatments.

a. for adult females (A), larvae plus nymphs (LN), and eggs (E) at the height interval 0-0.9 m.



b. for adult female mites on whole plants.

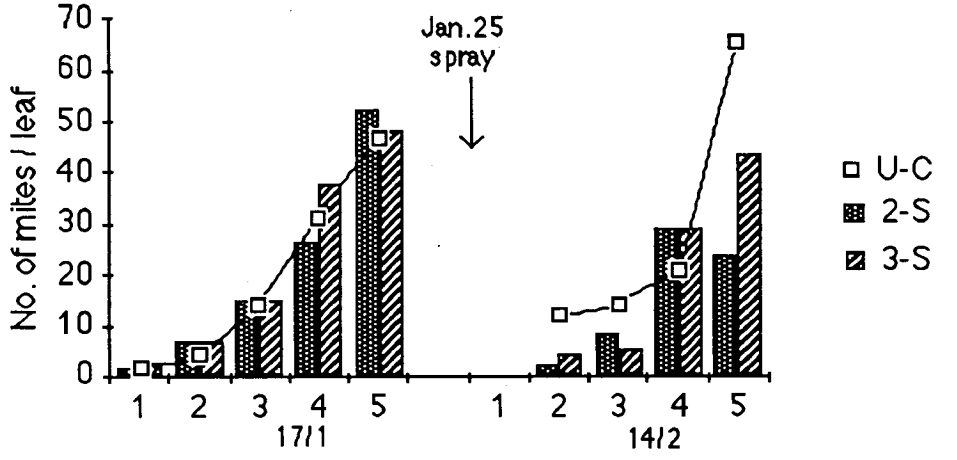


Note:

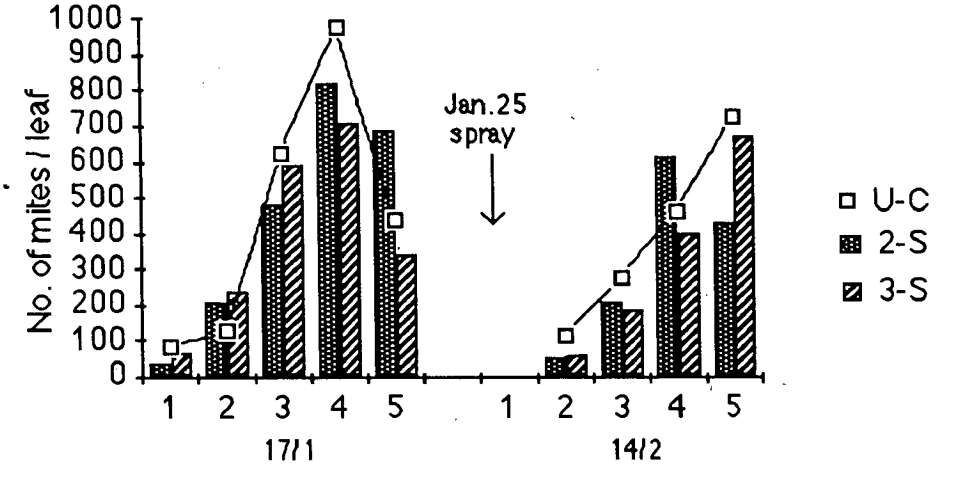
U-C = untreated control, plant no's. 6, 8, 12, 14, 35, 39, and 41;
2-O = plants receiving two sprays of Summer-oil, no's. 5, 9, 11, 24 & 34;
3-O = plants receiving three sprays of Summer-oil, no's. 2, 17, 19, 30, and 32.

Fig. 5.8 The effect of a third spray of Lime-sulphur on TSSM populations.

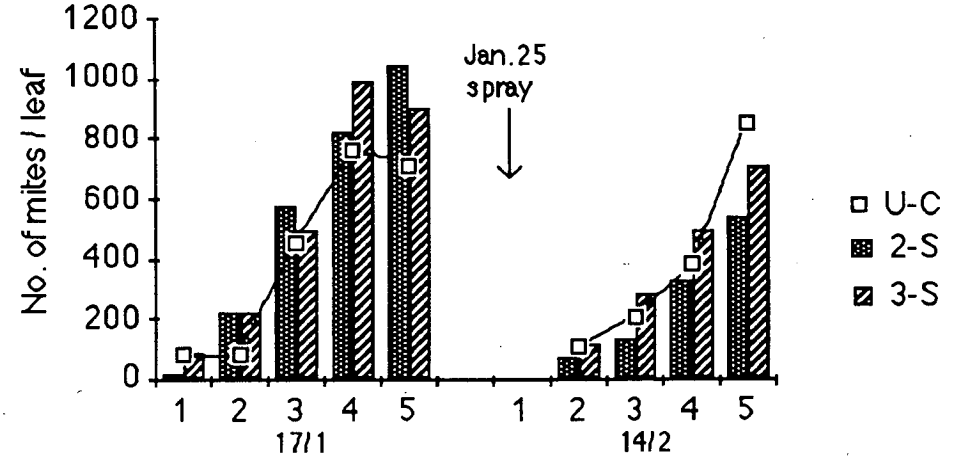
a. on populations of adult female mites.



b. on populations of larvae plus nymphs.



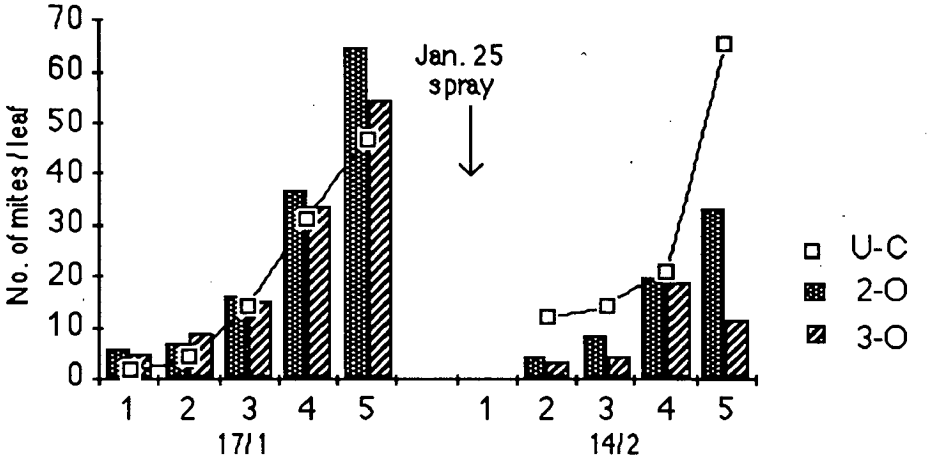
c. on populations of eggs.



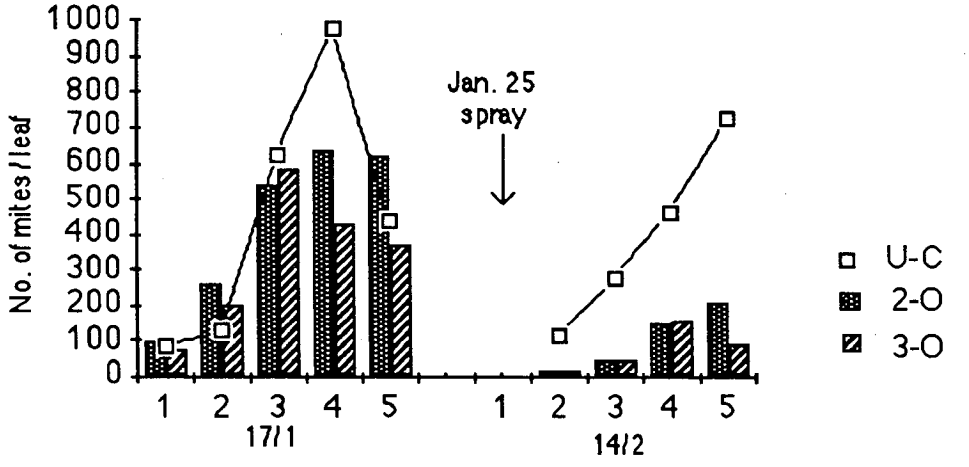
Note: height intervals 1 = 0-0.9 m; 2 = 0.9-1.8 m; 3 = 1.8-2.7 m;
4 = 2.7-3.6 m; 5 = 3.6-5.0 m.

Fig. 5.9. The effetc of a third spray of Summer-oil on TSSM populations.

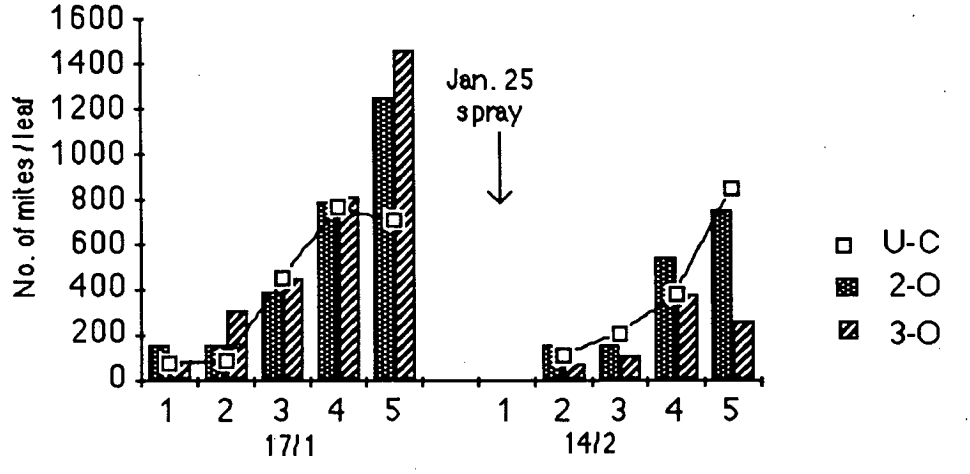
a. on populations of adult female mites.



b. on populations of larvae plus nymphs.



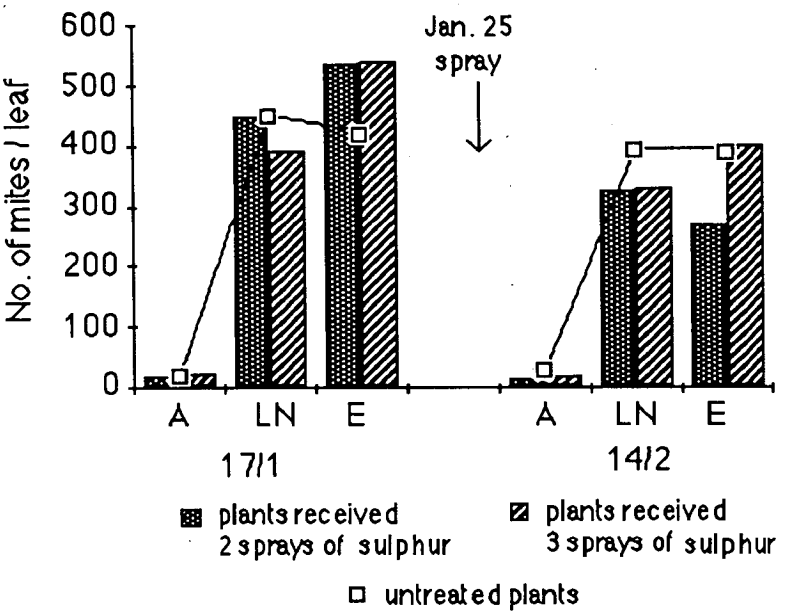
c. on populations of eggs.



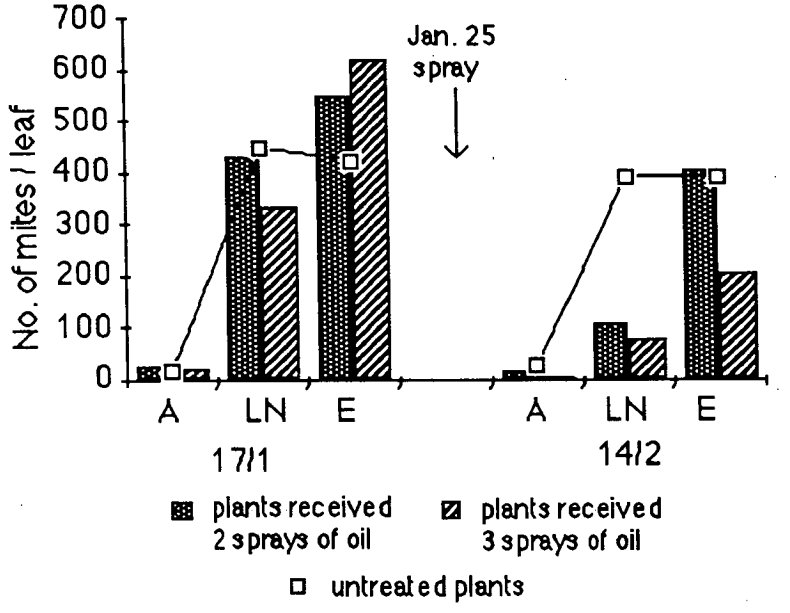
Note: height intervals 1 = 0-0.9 m; 2 = 0.9-1.8 m; 3 = 1.8-2.7 m;
4 = 2.7-3.6 m; 5 = 3.6-5.0 m.

Fig. 5.10. The effects of the third spray on TSSM populations on whole plants.

a. of Lime-sulphur spray.



b. of Summer-oil spray.



5.3.2. The Effect of Releasing *Phytoseiulus persimilis*

Before the release of the predator, both on November 5 (Fig. 5.11.) and December 2 (Fig.5.12.), TSSM populations were higher on plants which would receive the release of the predator later, than those on untreated plants. Some five weeks after the release, the predator had established on hops and demonstrated its efficiency in suppressing the population growth of TSSM. Fig. 5.13. compares the different TSSM stages in various height intervals sampled on January 17, 1988. Clearly, except in the height interval 3.6-5.0 m, the numbers of eggs, larvae and nymphs, and adult females in the other four intervals were all higher in the untreated controls than those on treated plants. In fact, the differences were quite apparent in the intervals of 1.8-2.7 m. and 2.7-3.6 m. Although the numbers of TSSM were higher in the top interval 3.6-5.0 m of treated plants, whole plant averages of TSSM were lower for treated plants than those on untreated plants (Fig. 5.14.a). An incomplete outline is given in Fig. 5.14.b. for the population changes of adult female mites of TSSM, for treated and untreated plants throughout the season in 1987-1988. Although it shows only the changes of adult female mites, it is still of significance in understanding the population changes of all mite stages of TSSM (see later 5.3.4.).

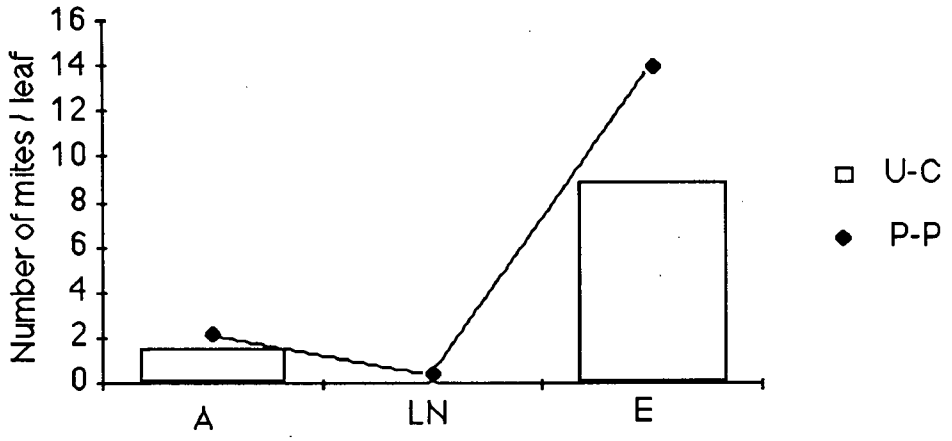
Fig. 5.15. shows the numbers per leaf and the vertical dispersion of *P. persimilis* in association with that of all TSSM stages and also the numbers and dispersion of predators on untreated plants.

A native predatory mite, *Amblyseius longispinosus* (Evans), was recovered in hops, but was not seen until the TSSM population became fairly well established and then in very low number.

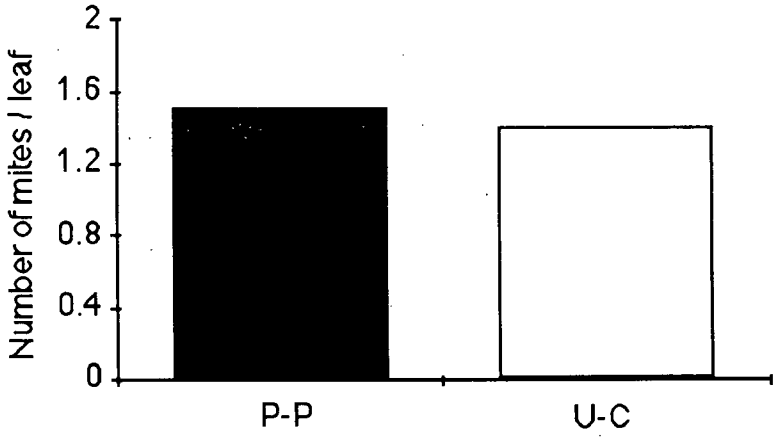
The native predatory beetle, *Stethorus* sp. was observed on hops even later and in much less numbers than *A. longispinosus*.

Fig. 5.11. Comparisons of the initial TSSM population size (sampled on November 5, 1987) on U-C* and P-P*.

a. for adult females (A), larvae plus nymphs (LN) and eggs (E) at the height interval 0-0.9 m.



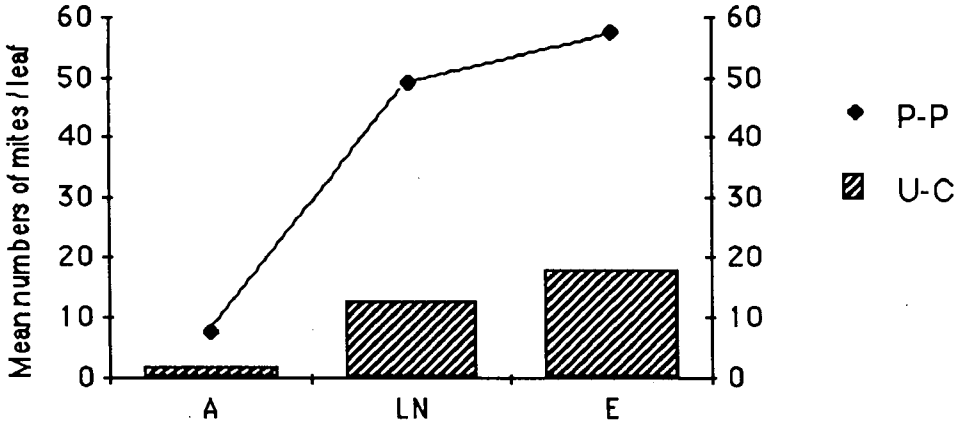
b. for adult female mites on whole plants



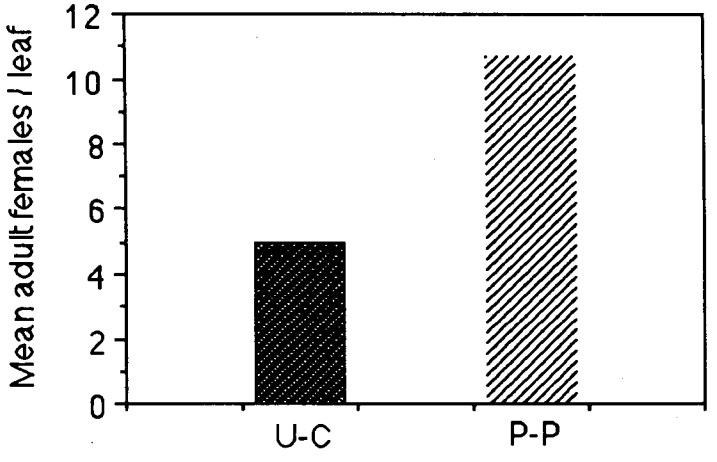
*: U-C = untreated control, plant no's. 6, 8, 12, 14, 35, 39, and 41;
P-P = plants with *Phytoseiulus persimilis* , plants no's. 1, 16, 21, 22, 26, 28, and 33.

Fig. 5.12. Comparisons* of TSSM densities between untreated control (U-C) and plants to receive *P. persimilis* (P-P).

a. comparison of mean numbers of adult females (A), larvae plus nymphs (LN) and eggs (E) per leaf for the height interval 0-0.9 m.



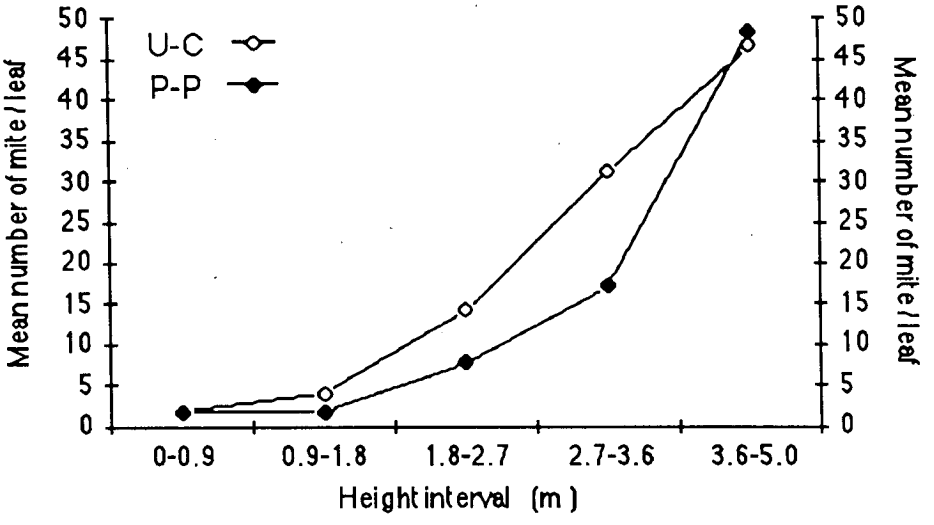
b. comparison of mean adult females / leaf on whole plants.



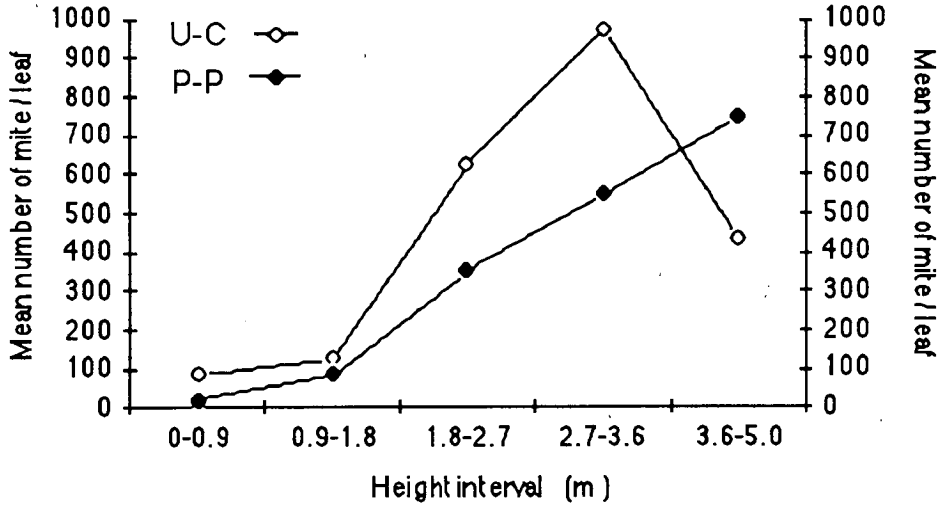
*: Sampling occurred on December 2, 1987, eight days before the release of the predators.

Fig. 5.13. Comparisons* of mean mite numbers per leaf in height intervals between untreated control (U-C) and plants with *Phytoseiulus persimilis* (P-P).

a. for adult female mites.



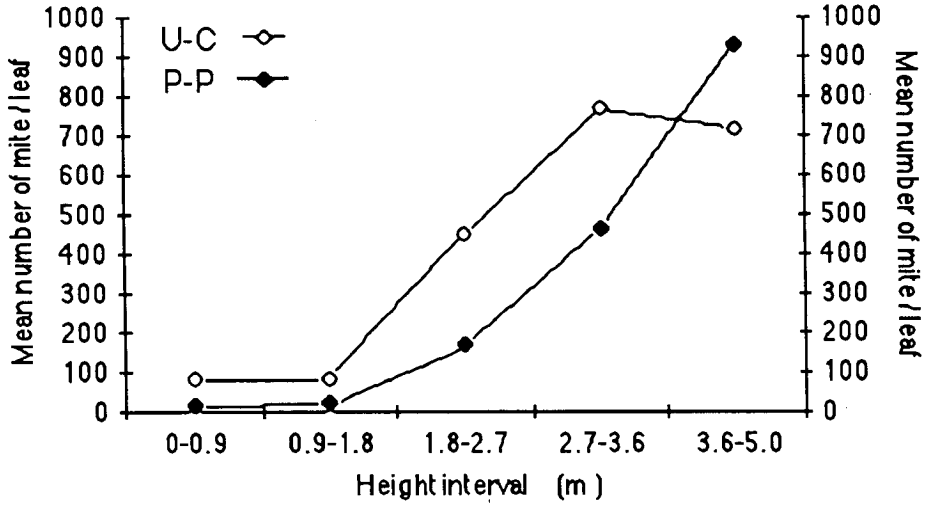
b. for larvae plus nymphs



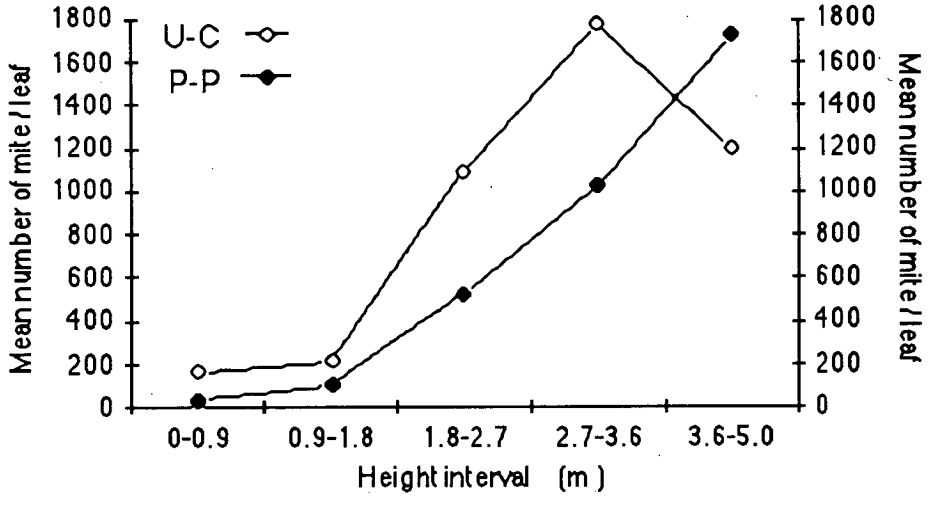
*: Sampling occurred on January 17, 1988, 38-days after the release of the predators.

Fig. 5.13. Comparisons* of mean mite numbers per leaf in height intervals between untreated control (U-C) and plants with *Phytoseiulus persimilis* (P-P). *(continued)*

c. for eggs.



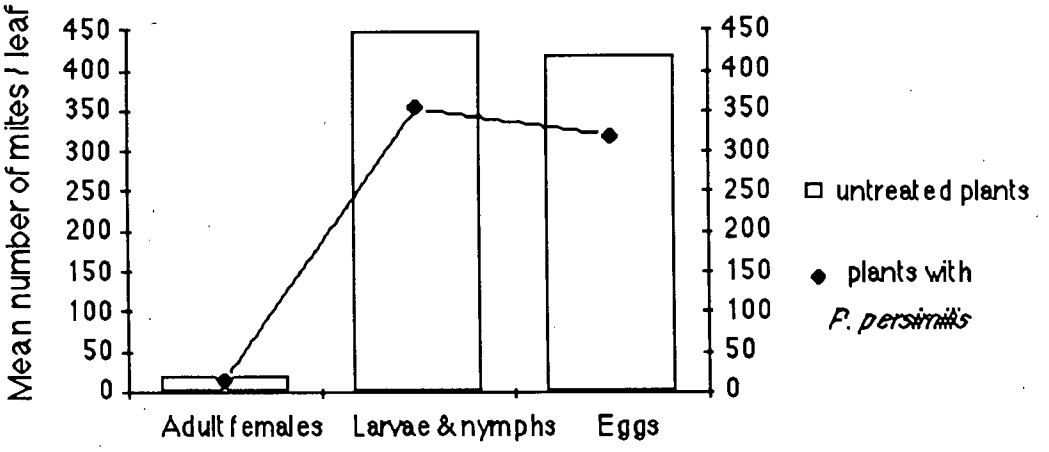
d. for sum of all mite stages.



*: Sampling occurred on January 17, 1988, 38-days after the release of the predators.

Fig. 5.14. Comparison of TSSM populations between untreated control (U-C) and plants with *P. persimilis* (P-P).

a. for all mite stages on whole plants, sampled on January 17, 1988.



b. for population changes of adult female mites, on whole plants, in the year of 1987-1988.

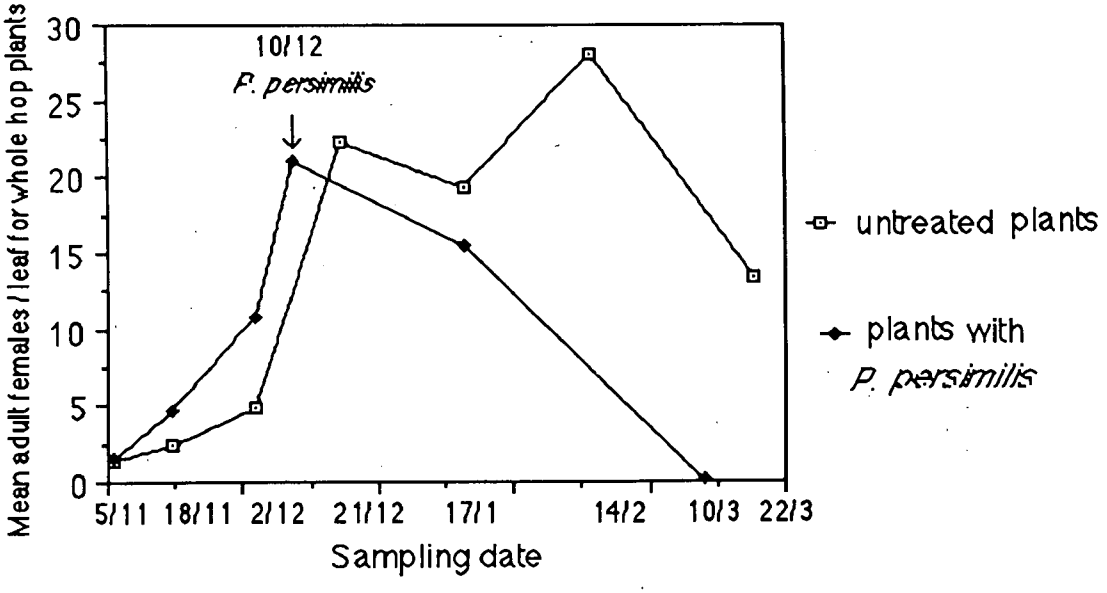
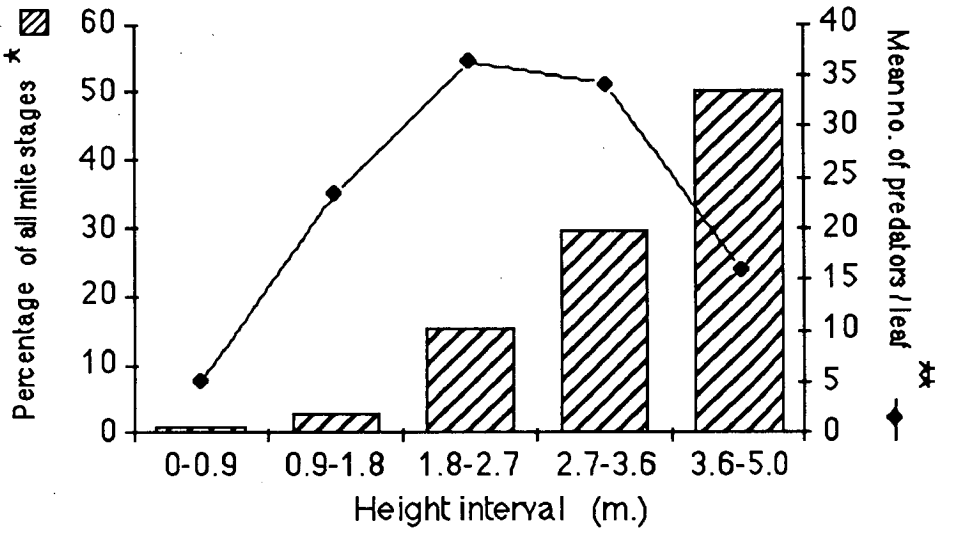
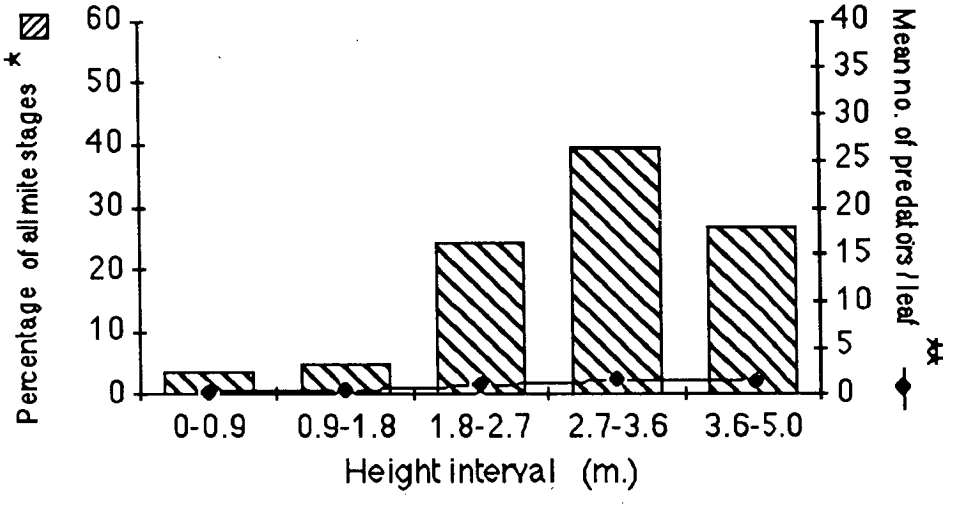


Fig. 5.15. The relationship between the densities of predators and the distribution of TSSM on hop plants.

a. for plants with *P. persimilis* (P-P).



b. for untreated control (U-C) plants.



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*: The percentages are the proportions of mites/leaf of each interval in the sum of mites/leaf for all intervals;

: This is the sum of mites/leaf for three predators, *P. persimilis*, *A. longispinosus*, and *Stethorus* sp.. In **a., 85 per cent the sum is *P. persimilis*, while in **b.** there is hardly any *P. persimilis* present.

5.3.3. The Vertical Dispersion of TSSM on Hops

During sampling throughout the growing season, it was observed that the general trend in the dispersion of TSSM on hops was to move upwards. After overwintering, the mite gathered on hops when the host plants were short and small. Overwintered female mites stayed at the base and laid their eggs there. Later, teneral females of the new generation dispersed vertically upwards to the newly expanded leaves, as the hop plant elongated. However it was noticed that before the plants reached their full length, there always existed a certain distance between the tip of the plants and the height to where the mites had reached (This height will be subsequently abbreviated to 'mite height'). This distance could be more suitably expressed in terms of the number of nodes on the upper part of the plant, for it was found that the number of nodes between the plant tip and the mite height was generally 4-7, varying with the numbers of mites on the plant. Very rarely did 'mite height' reach the 4th node from the plant tip, for at the level of the 4th node leaves were always just fully expanded and still very small, and therefore possibly not mature enough to provide adequate nutrition and, perhaps, protection for the mite.

A series of graphs showing the vertical dispersion of adult female mites throughout the season are given for different treatments from Figs. 5.16. to 20. (There were some differences in the dispersion pattern of eggs, larvae and nymphs, and adult female mites, but only the pattern of adult females is presented here. See later 5.3.4. for more details.).

At the beginning of sampling, all hop plants were on average about 125-165 cm. in length with the 'mite height' about 90-110, with similar patterns of mite dispersion, for the five different plant groups (a.'s in Figs. 5.16.-20.).

Twelve days after the first sprays on November 6, 1987, these dispersion patterns became variable. The differences between plants height and mite height were 62 cm (plant height minus mite height: 249-187) for the untreated plants, 90 cm (242-152) for sulphur-two-spray plants, 56 cm (195-139) for sulphur-three-spray plants, 115 cm (243-128) for oil-two-spray plants, and 91 cm (224-133) for oil-three-spray plants. Meanwhile the percent proportions of adult female mites in height intervals were also changed (Figs. 5.16.-20., b.'s).

Fig. 5.16. shows that the majority of the population of adult female mites shifted gradually towards the growing tip of hop plants. But in Figs. 5.17.-20., there appeared certain variations. Therefore, it was believed that the sprays of lime-sulphur and summer-oil not only retarded the upward movement of adult female mites on hop plants, but also changed the proportions of the mite in certain height intervals.

In fact, as it is a general trend for adult female mites to leave their family territory and move upwards to look for new habitats, there inevitably resulted in some differences in the distribution patterns of adult females, larvae plus nymphs for the different height intervals. Often it was found that the majority of larvae and nymphs were in the interval next to the interval having the majority of adult female mites. Obviously, eggs are always associated with adult female mites.

Fig. 5.16. Distribution of adult female TSSM on untreated control (U-C) plants throughout the year of 1987-1988.

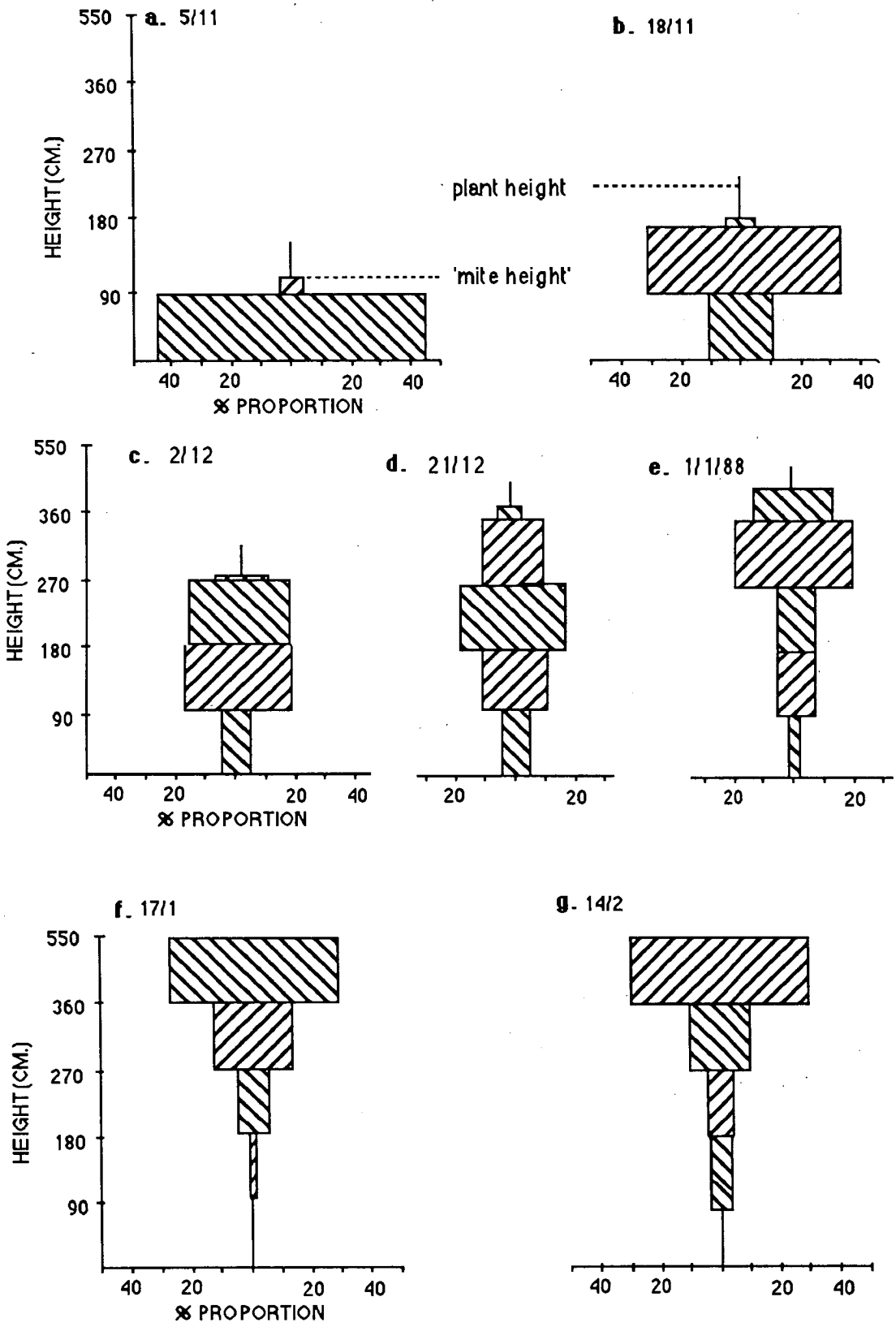


Fig. 5.17. Distribution of adult female TSSM on hop plants (2-S) in 1987-88.

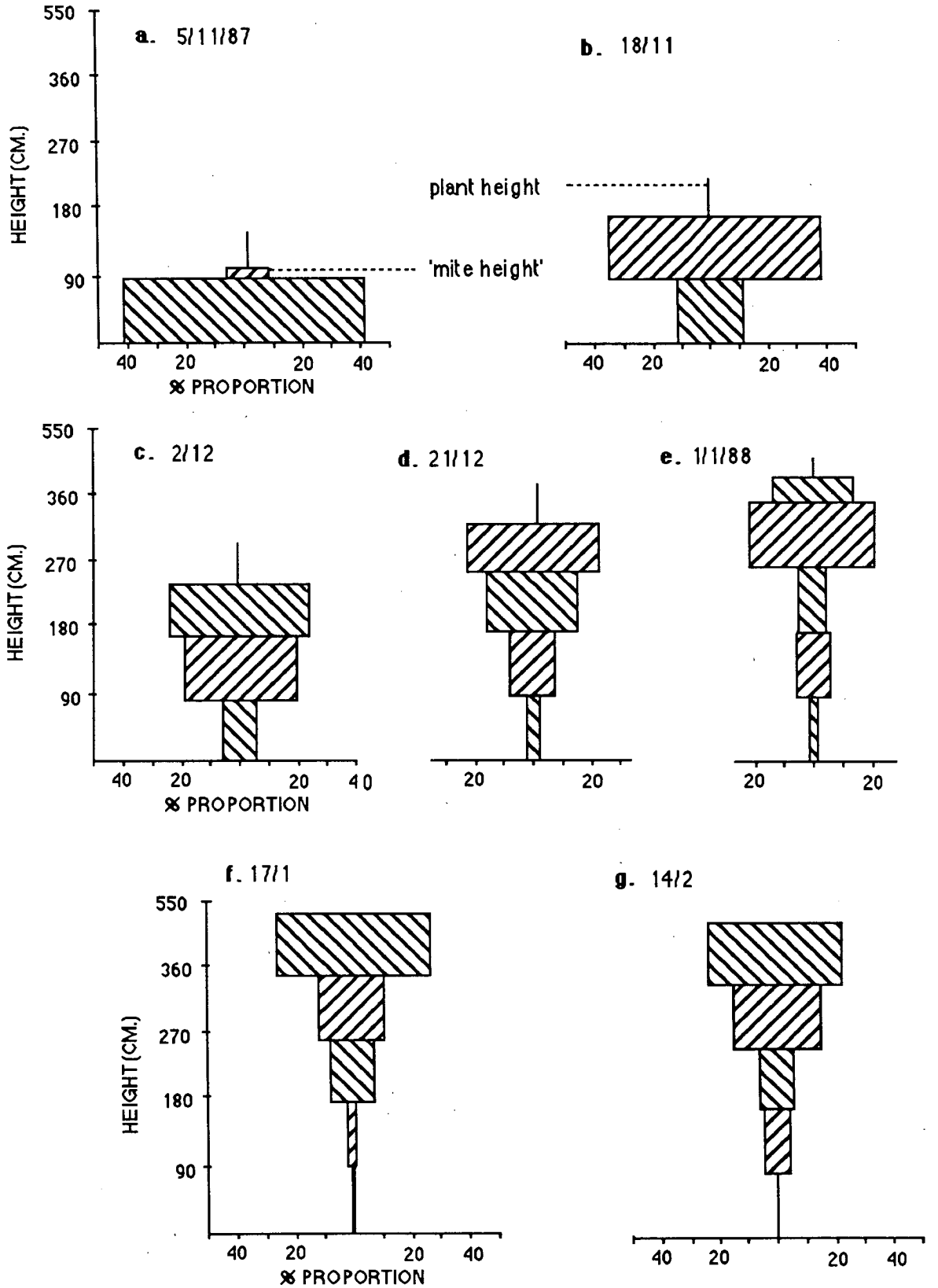


Fig. 5.18. Distribution of adult female TSSM on hop plants (3-S) in 1987-88.

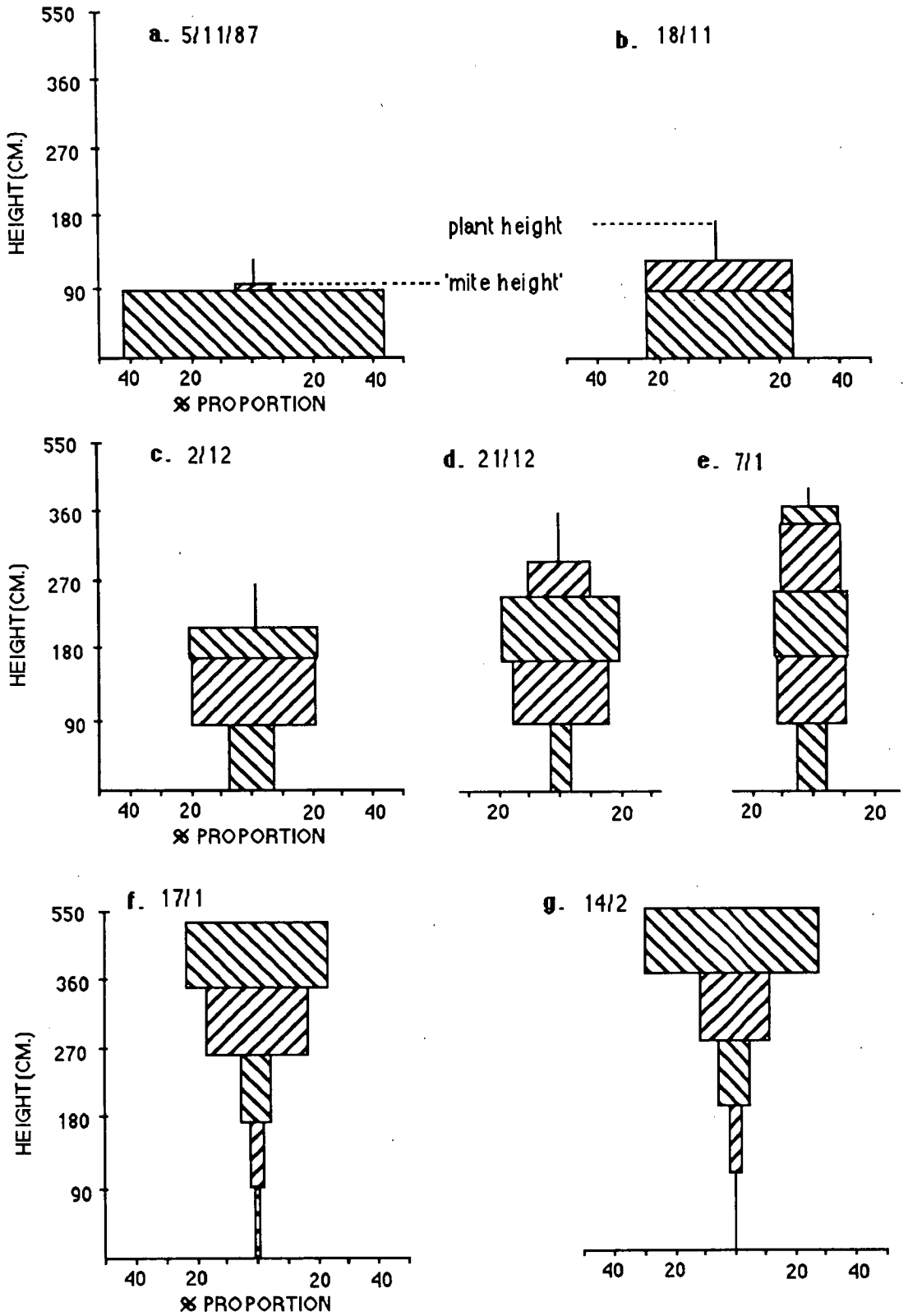


Fig. 5.19. Distribution of adult female TSSM on hop plants (2-O) in 1987-88.

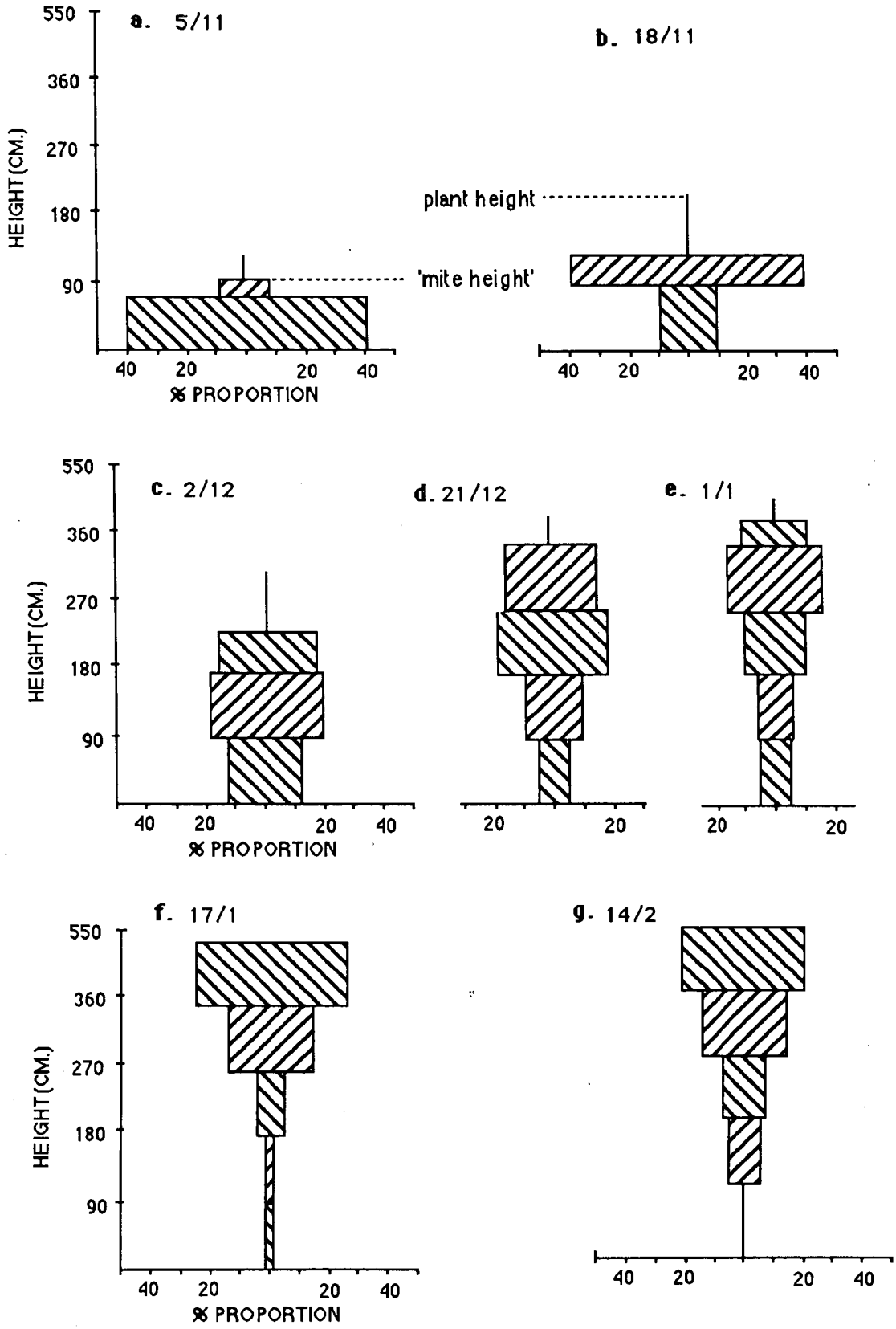
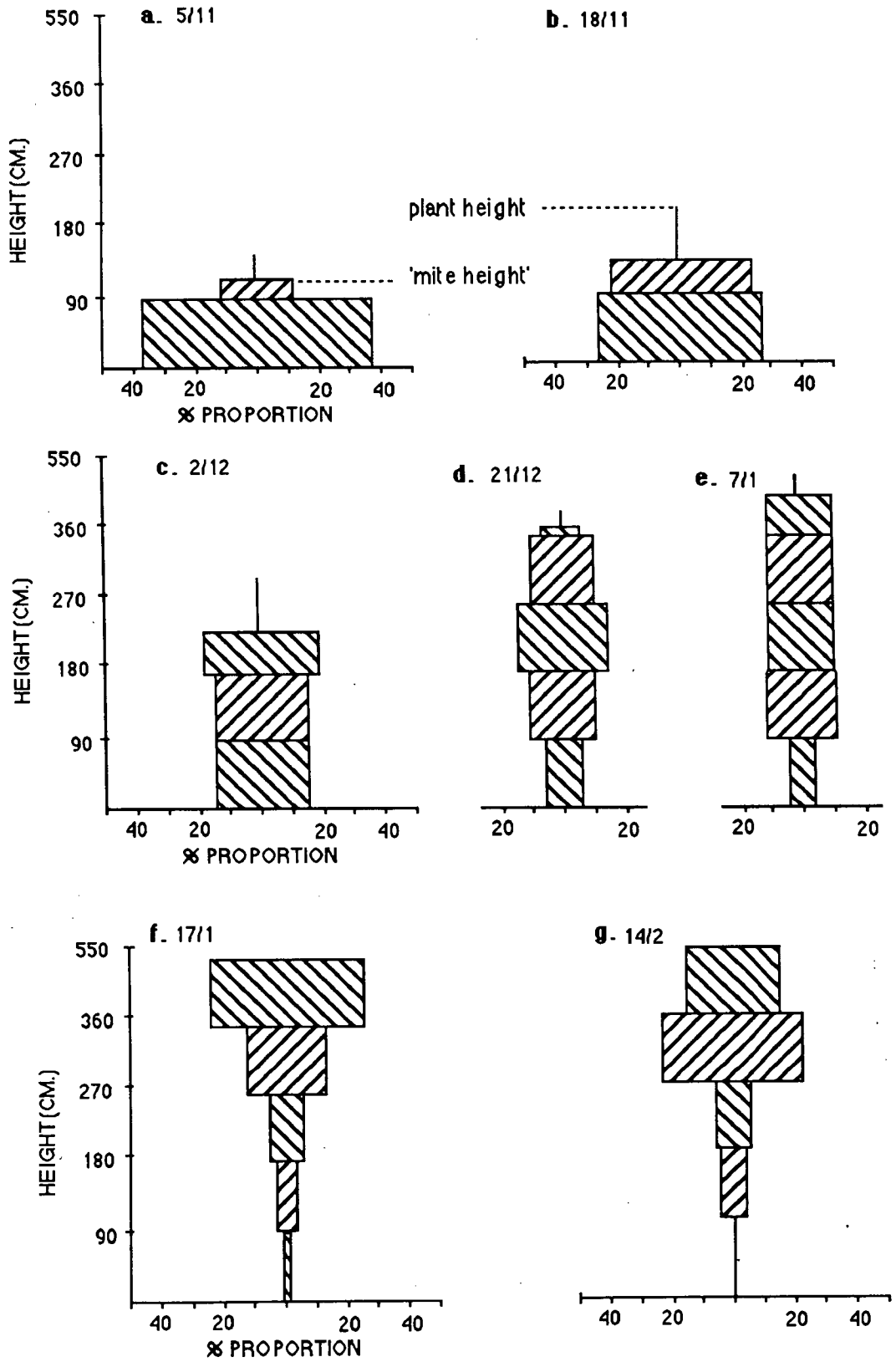


Fig. 5.20. Distribution of adult female TSSM on hop plants (3-O) in 1987-88.



5.3.4. Stage Composition of Mite Populations

It was observed that the composition of mite populations (i.e., the proportions of eggs, larvae plus nymphs, and adult female mites in a given population) varied with time and height interval.

Fig. 5.21. shows the composition of the original mite populations for six different treatments at the early stage of their development. It is evident that at commencement, the most abundant stage in all six populations was eggs, ranging from 80-90 per cent. The proportion of adult female mites was about 10-16 per cent; whereas there were very few larvae and nymphs, 0-4 per cent. It is manifest that these percentages represent young and initial mite populations.

In Table 5.4., progressive changes in the composition of mite population are sequentially presented from November 5 to December 21, 1987 for the different treatments in the height interval 0-0.9 m.. It can be easily seen that from November 5 to December 21, 1987, the composition of the mite populations on untreated plants changed such that the proportion of eggs became smaller and smaller while the proportion of larvae plus nymphs larger and larger. There was hardly any differences in populations on plants on which predators would be released and which been left untreated until December 10. In the other treatments, similar dispersion patterns were observed with the exception of those plants sprayed with lime-sulphur and summer-oil. These sprays had a strong influence on checking the increase in the proportion of larvae and nymphs

within populations.

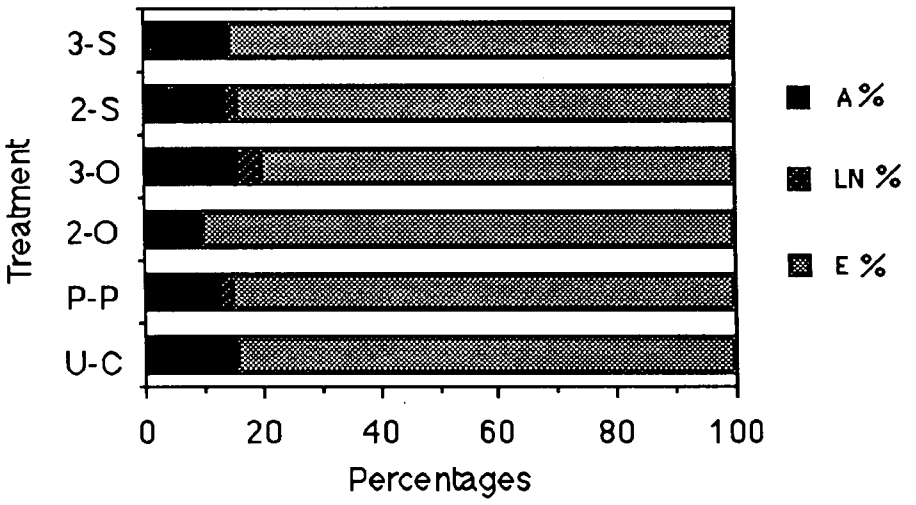
Table 5.4. also lists the composition of mite populations in the height interval 1.8-2.7 m for various treatments sampled on January 1 and 7, 1988, and the stage composition on whole plants for treatments C-S, P-P, and U-C at various time of March 1988. Obviously, different treatments resulted in variations in the proportions of the three components.

On January 17 and February 14, 1988, hop plants were sampled in such a way that all mite stages were censused for all height intervals and all treatments, enabling comparison of the overall differences of mite populations in different heights and treatments. The number of all stages of mites per leaf and the percentage components from the two samplings are presented in Table 5.5..

It was noted that the most severely damaged leaves were always associated with mite populations having a very high proportion of larvae and nymphs, but rarely with mite populations having a high proportion of eggs.

A great amount of variation in the stage composition of mite populations can be seen in Tables 5.4. and 5., following the application of various control measures. However, it was found that an average age structure of 1.5-2.0 per cent for adult female mites, 55 (51-60) per cent for larvae and nymphs, and 45 (38-47.5) per cent for eggs could be suggested as a mature and normally developed TSSM population on hop leaves.

Fig. 5.21. Comparison of the composition of initial mite populations (November 5, 1987) for six different treatments at the height interval 0-0.9 m.



Note:

3-S = plants to be sprayed with Lime-sulphur three times;

2-S = plants to be sprayed with Lime-sulphur two times;

3-O = plants to be sprayed with Summer-oil three times;

2-O = plants to be sprayed with Summer-oil two times;

P-P = plants to receive the release of *P. persimilis;*

U-C = untreated control plants.

Table 5.4. The stage composition of TSSM populations at various time.

Height intervals	Treatments	Sampling Date	Σ mites / leaf	A%	LN%	E%
0-0.9 m.		November 5, 1987				
	U-C		10.5	15.3	0	84.7
	P-P		16.5	12.7	2.1	85.2
	2-S		13.3	13.9	1.8	84.3
	3-S		17.3	14.3	0	85.7
	2-O		10.9	9.6	0	90.4
	3-O		21.2	15.8	3.8	80.4
		November 18, 1987				
	U-C		41.1	2.9	28.3	68.8
	P-P		90.0	2.8	29.1	68.1
	2-S		3.5	21.0	2.0	77.0
	3-S		21.0	9.5	4.8	85.7
	2-O		0.26	50	0	50.0
	3-O		15.6	7.7	8.3	84.0
		December 2, 1987				
	U-C		32.6	5.5	39.1	55.4
	P-P		114.6	6.8	43.1	50.1
	2-S		20.8	8.7	36.5	54.8
	3-S		21.1	18.5	21.3	60.2
	2-O		12.9	14.0	2.6	83.4
	3-O		22.0	12.4	24.3	63.3
		December 21, 197				
	U-C		61.3	8.0	54.5	37.5
	2-S		57.2	4.8	45.6	49.6
	3-S		36.5	5.3	31.1	63.6
	2-O		57.7	10.4	41.6	48.0
	3-O		43.9	11.1	0	88.9
		Jan. 1, 1988				
1.8-2.7 m.	U-C		1072.4	1.2	23.4	75.4
	2-S		1103.7	1.7	46.9	51.4
	2-O		808.5	1.2	34.9	63.9
		Jan. 7, 1988				
	3-S		796.2	4.5	62.9	32.6
	3-O		889.0	4.1	40.2	55.7
Whole	C-S	Mar. 3	174.3	6.4	39.1	54.5
Plant	P-P	Mar. 10	5.8	6.1	63.5	30.4
	U-C	Mar. 22	90.9	14.7	71.6	13.7

Table 5.5. The percentages of adult female mites (A), larvae plus nymphs (LN), and eggs (E) in mite populations for untreated control (U-C), lime-sulphur two sprays (2-S) and three sprays (3-S), summer-oil two sprays (2-O) and three sprays (3-O).

Sampling date		Jan. 17, 1988				Feb. 14, 1988			
Height intervals	Treatments	Σ mites / leaf	A%	LN%	E%	Σ mites/leaf	A%	LN%	E%
3.6-5.0 m.	U-C	1197	3.9	36.4	59.7	1642.9	4.0	44	52
	P-P	1727.2	2.8	43.4	53.8	-	-	-	-
	2-S	1789.3	2.9	38.7	58.4	995.3	2.4	43.3	54.3
	3-S	1297	3.7	26.5	69.8	1430.3	3.1	47.1	49.8
	2-O	1936	3.3	32.1	64.6	1007.9	3.3	21.0	75.7
	3-O	1889.8	2.9	19.8	77.3	359.5	3.3	24.6	72.2
2.7-3.6 m.	U-C	1773.8	1.8	55.0	43.2	865.8	2.4	53.3	44.3
	P-P	1029.1	1.7	53.5	44.8	-	-	-	-
	2-S	1680	1.6	49	49.4	972.3	3.0	63.1	33.9
	3-S	1743.6	2.2	40.7	57.1	927.7	3.2	43.4	53.4
	2-O	1469.6	2.5	43.2	54.3	715.2	2.8	21.5	75.7
	3-O	1280.9	2.7	33.9	63.4	494.6	3.8	31.8	64.4
1.8-2.7 m.	U-C	1089.7	1.3	57.4	41.3	504	2.8	55.4	41.8
	P-P	532	1.5	67.0	31.5	-	-	-	-
	2-S	1072	1.4	44.8	53.8	351.4	2.4	53.2	44.2
	3-S	1105	1.4	53.4	45.2	486.1	1.1	39.2	59.7
	2-O	955	1.7	56.8	41.5	213	4.0	22.4	73.6
	3-O	1059.7	1.4	55.4	43.2	165.3	2.7	27.9	69.4
0.9-1.8 m.	U-C	217.6	1.9	58.6	39.5	234.3	5.1	47.4	47.5
	P-P	111.4	1.6	77.7	20.7	-	-	-	-
	2-S	434.7	1.5	47.5	51	130.7	1.8	40.3	57.9
	3-S	471.3	1.5	51.3	47.2	178.6	2.5	33.2	64.3
	2-O	427.8	1.6	61.1	37.3	188.8	2.3	11.3	86.4
	3-O	519.9	1.7	39.2	59.1	96.1	3.4	18.7	77.9
0-0.9 m.	U-C	168	1.0	51.0	48.0	-	-	-	-
	P-P	39.2	4.6	54.9	40.5	-	-	-	-
	2-S	60.3	2.7	61.2	36.2	-	-	-	-
	3-S	165.1	1.7	42.6	55.7	-	-	-	-
	2-O	262	2.2	38.3	59.5	-	-	-	-
	3-O	160.8	3.0	46.3	50.7	-	-	-	-

5.3.5. The Possibility of Cultural Control of TSSM

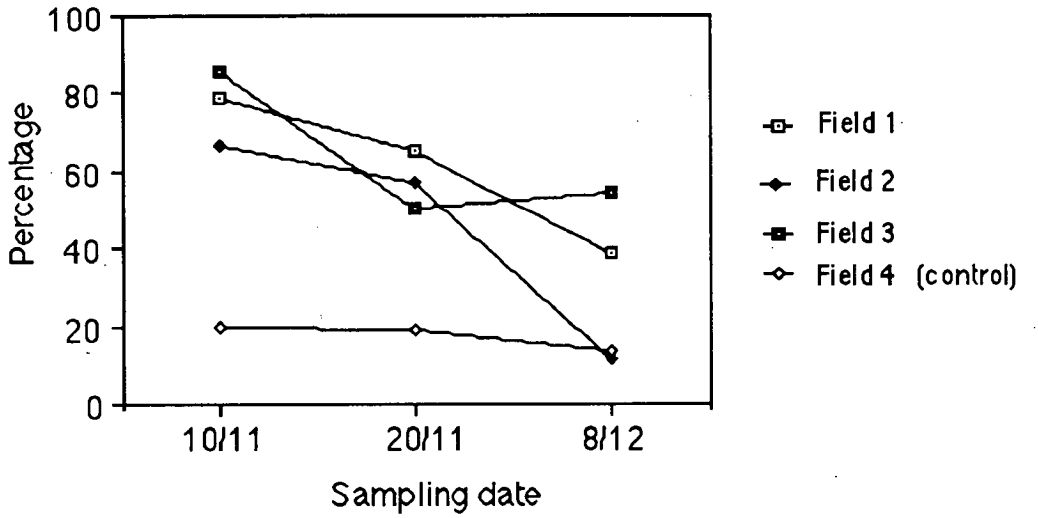
5.3.5.1. The appropriate time for early ploughing

The ploughing of three hop fields in early spring of 1988 resulted in encouraging consequences. Fig. 5.22. presents the comparison of the percentage of leaves with TSSM present or absent from three ploughed and one unploughed hop fields. It can be seen that the percentage of hop leaves occupied by TSSM were much higher on plants in the unploughed field (field 4) than those in the ploughed fields (fields 1, 2, and 3) on November 10, 1988. While the percentage of leaves infested on plants in the unploughed field remained almost constant, more and more leaves on plants in the ploughed fields became infested with TSSM.

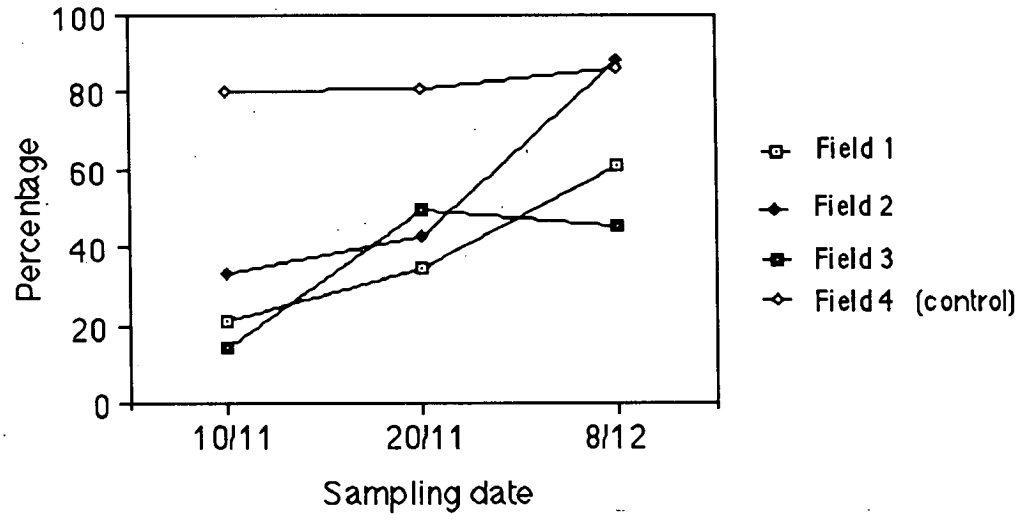
The variation of the numbers of mite stages from the four fields are presented in Fig. 5.23.. The numbers of eggs, larvae plus nymphs, and adult female mites were all higher on unploughed field plants than those on ploughed field plants, with the exception that numbers in ploughed field 2 were higher than all others on December 8. It was observed that after ploughing, there were more thistles in the unploughed field than in ploughed fields.

Fig. 5.22. Comparison of TSSM densities in hop fields cultivated in early season (Fields 1, 2, and 3) and uncultivated (Field 4).

a. percentages of leaves free from TSSM*.



b. percentages of leaves with TSSM*.



*: Number of leaves collected

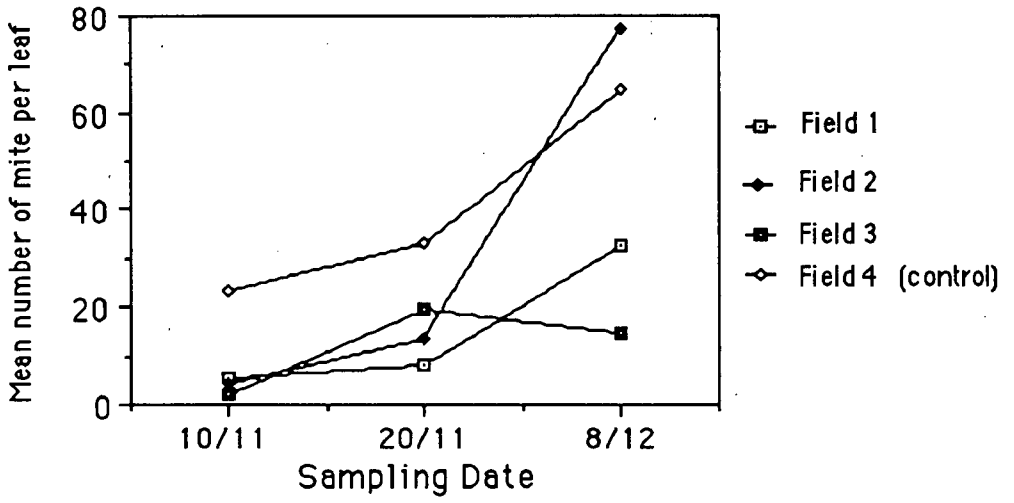
November 10, 1988: Field 1 100; Field 2 107; Field 3 104; Field 4 97.

November 20, 1988: Field 1 161; Field 2 156; Field 3 133; Field 4 121.

December 8, 1988: Field 1 80; Field 2 96; Field 3 111; Field 4 116.

Fig. 5.23. The variation of numbers of TSSM stages in cultivated and uncultivated hop fields.

a. for eggs.



b. for larvae plus nymphs.

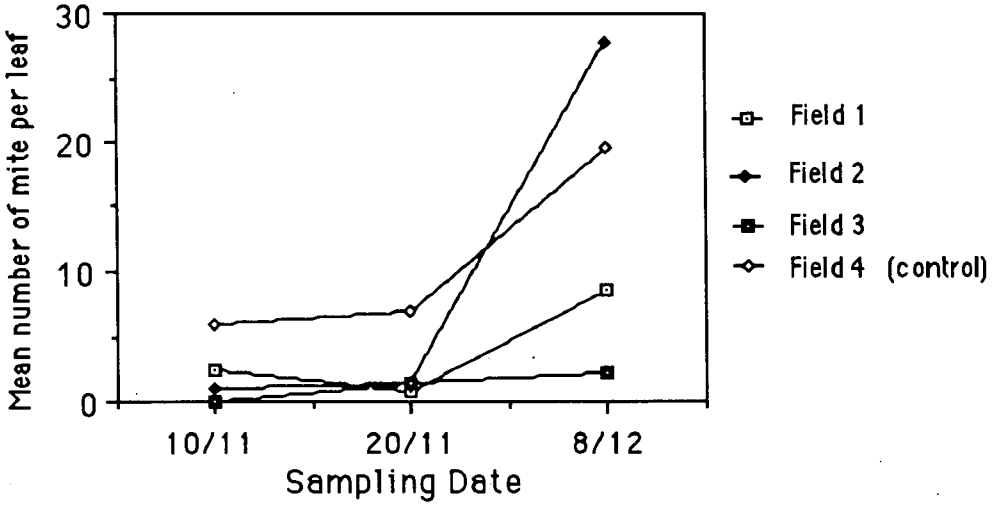
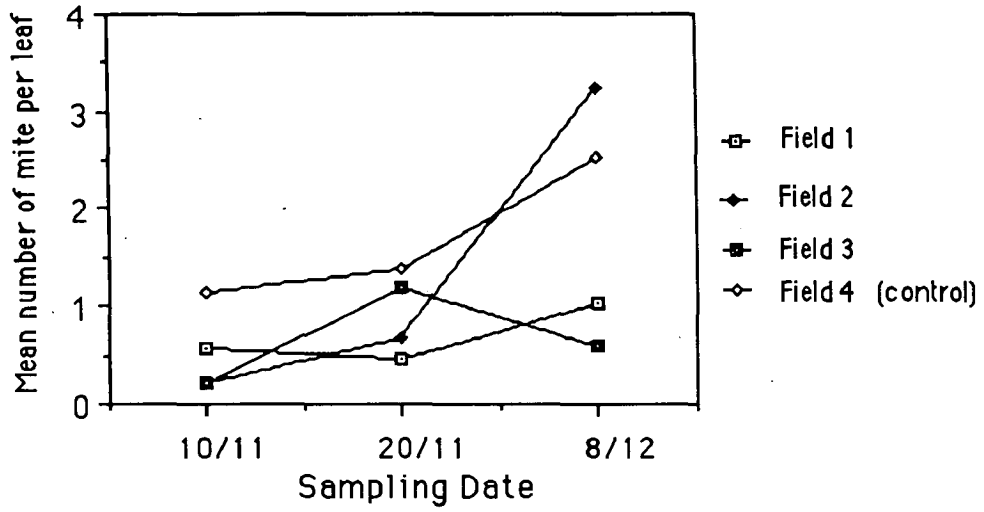
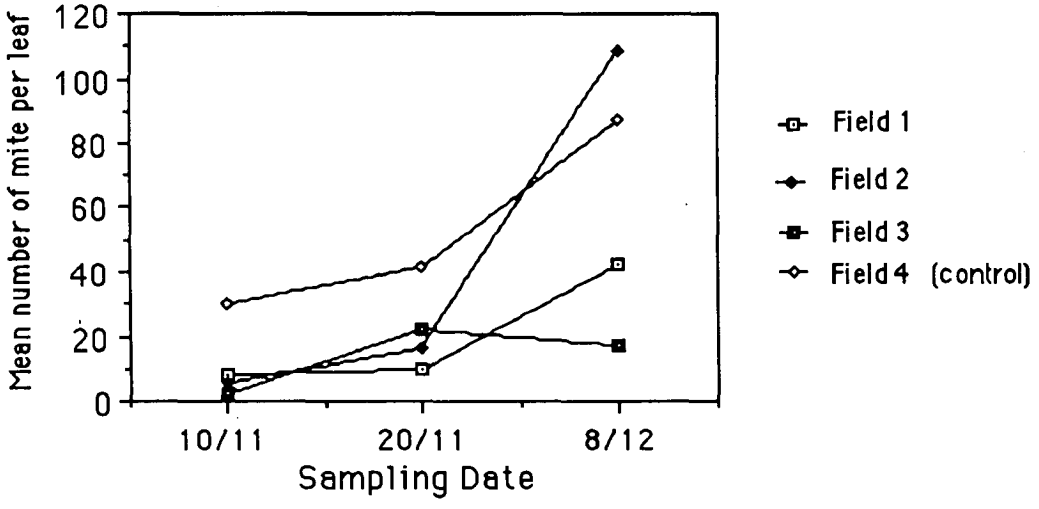


Fig. 5.23. The variation of numbers of TSSM stages in cultivated and uncultivated hop fields. *(continued)*

c. for adult female mites.



d. for all mite stages.



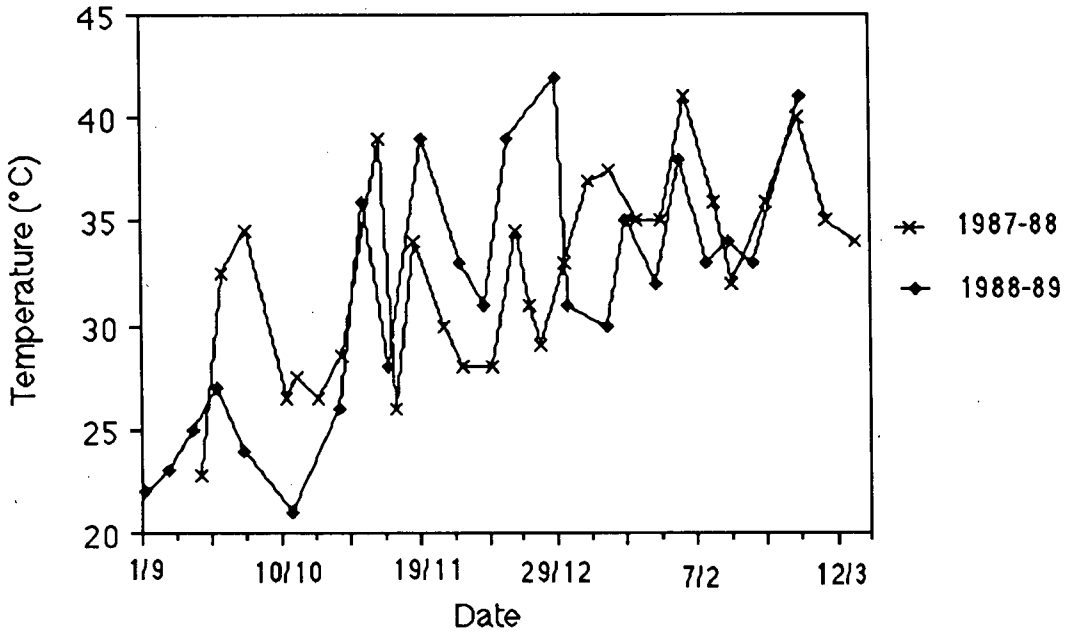
5.3.5.2. The development of TSSM populations and the growth of hops under various conditions

It was observed by the hop grower (Mr. T. Frankcombe) that the early stages of the growing season of 1987-88 were hotter and drier than usual, and that the infestation of TSSM was also higher. The late winter and early spring of 1988 was rather cold and damp. The comparison of the weekly maximum and minimum temperature in 1987-88 and 1988-89 is presented in Fig. 5.24.. In 1987, the first high temperature of 32.5°C occurred between September 17 and 23, and this increased to 34.5°C on September 30. In 1988, temperatures did not exceed 30°C until November 3, when 36°C was recorded, i.e., approximately six weeks later than in 1987. From Fig. 5.24.a., it can be seen that in the period from mid- September to early November, the maximum temperatures in 1987 were higher than those in 1988. The cumulative monthly rainfall in these two consecutive seasons are given in Fig. 5.25., and it is obvious that rainfall played quite an important role in the revival of overwintering TSSM and the early stage of plant/TSSM development.

The population dynamics of TSSM in hops between 1987-1988 and 1988-1989 were markedly different in the time when mites first became active and the way in which the mite populations developed, as shown in Fig. 5. 26.. In the season of 1987-88, sampling of TSSM infestation of hop leaves commenced on November 5, 1987. In the following season, infestation was not apparent until November 20 1988, two weeks later than in the previous season. The gradual decrease of mite populations from the middle of December of 1988 was suspected to be related to the irrigation of hop fields. In the season of 1988-89, the grower was able to irrigate hop fields properly

Fig. 5.24. The comparison of weekly maximum and minimum temperatures in hop field for two consecutive growing seasons (1987-88 and 1988-89).

a. for maximum temperature.



b. for minimum temperature.

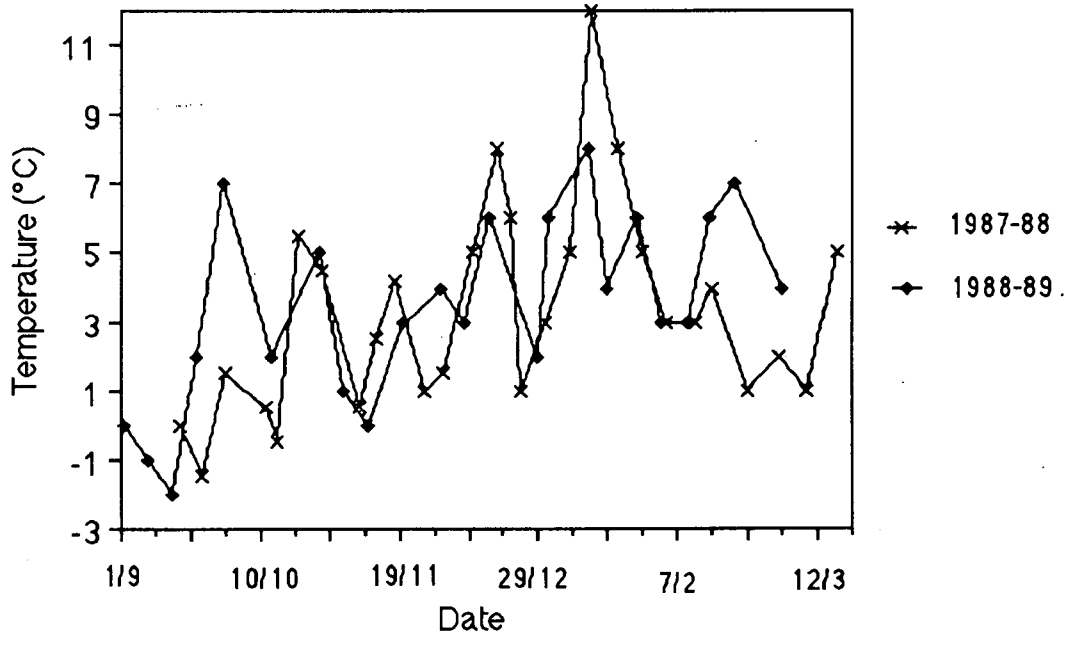


Fig. 5.25. The monthly rainfall for the two growing seasons (1987-88 and 1988-89).

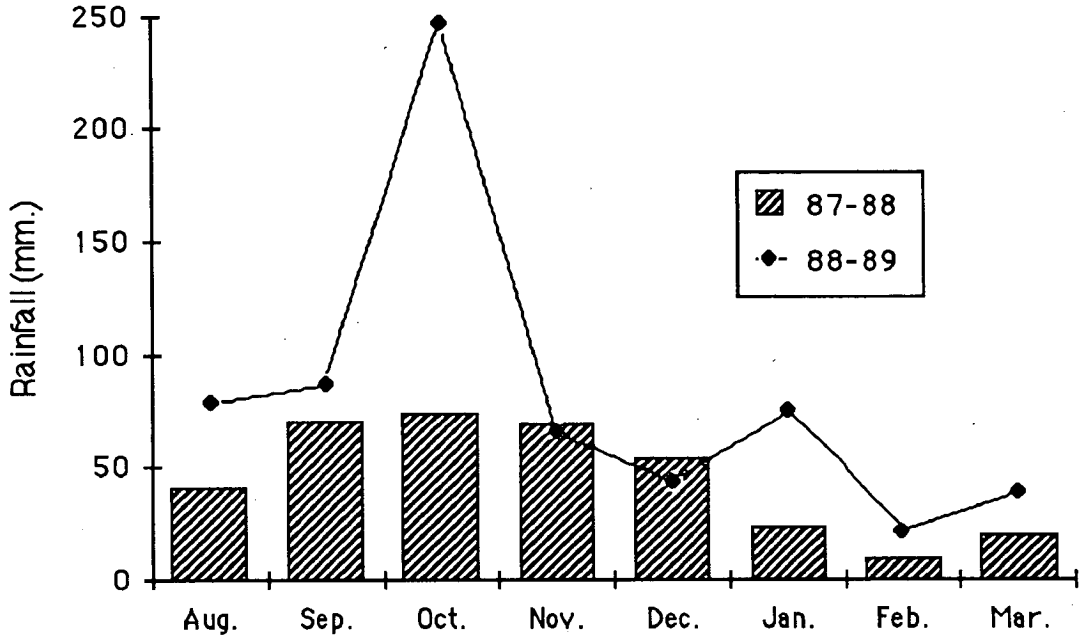
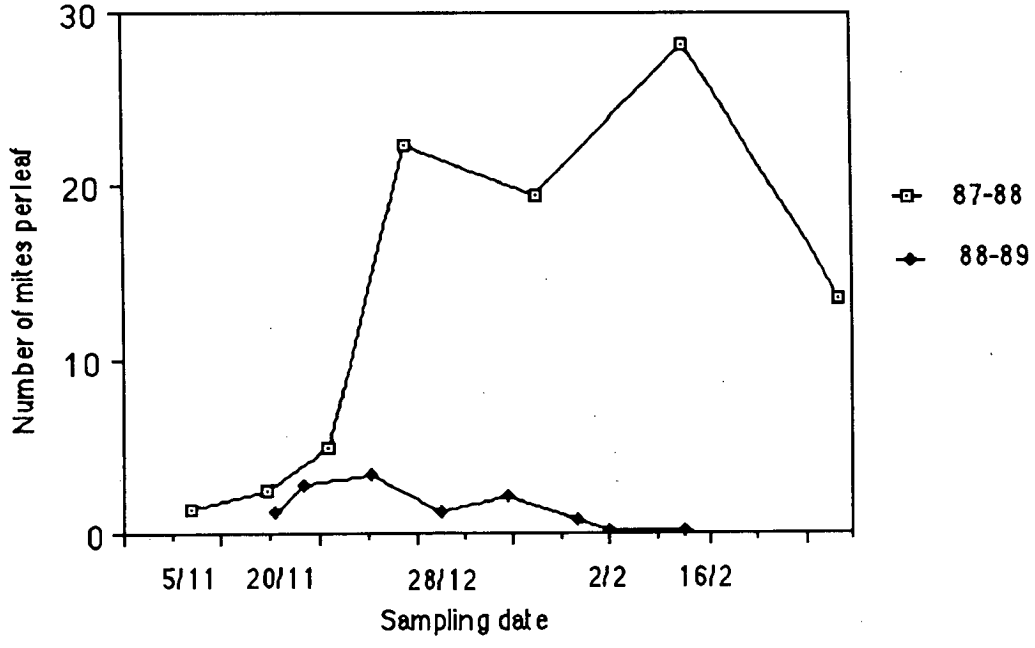


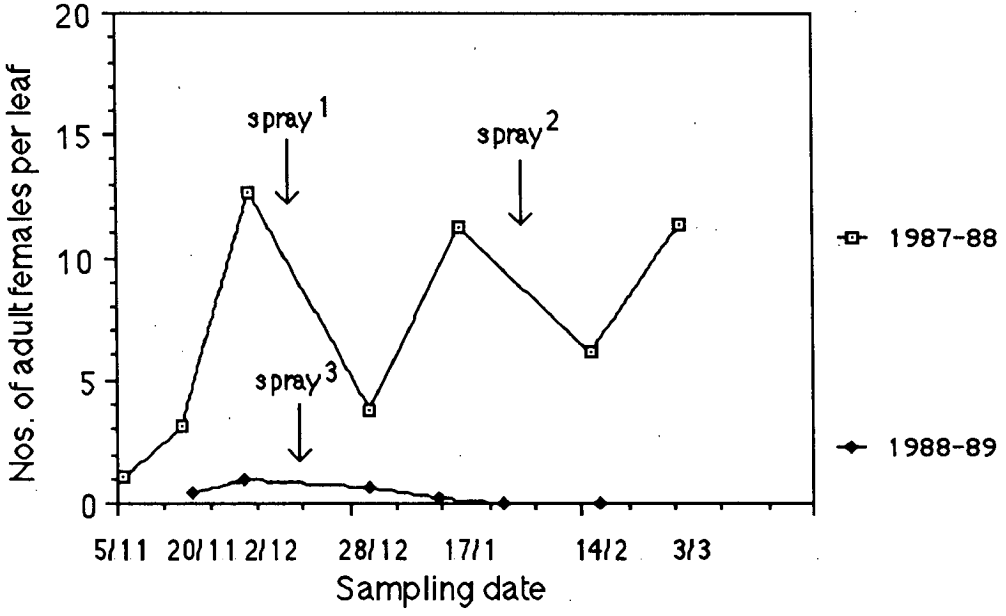
Fig. 5.26. The population changes of adult female TSSM on hops (untreated control plants) for the two seasons (1987-88 and 1988-89).



and to keep the fields moist all the time. In the previous season, this cultural activity was not satisfactorily carried out due to the low flow of water in the local river. The schedule of this irrigation in 1988-89 was 12 hours watering every eight days, which was initiated around December 15 1988 and maintained until late in the season before harvest. The relative humidity measured in the trial plot at various time were: 55-60% when sprinklers were 40-50 m away (the maximum distance between the trial plot and sprinklers) from the plot; 60-70% when it was 20 m away; and 80-90% when sprinklers were in or very close to the trial plot.

Tremendous difference occurred in the growth of mite populations in the two seasons. The population changes of adult female mites on commercially sprayed crops, throughout the growing seasons of 1987-88 and 1988-89 are given in Fig. 5.27..

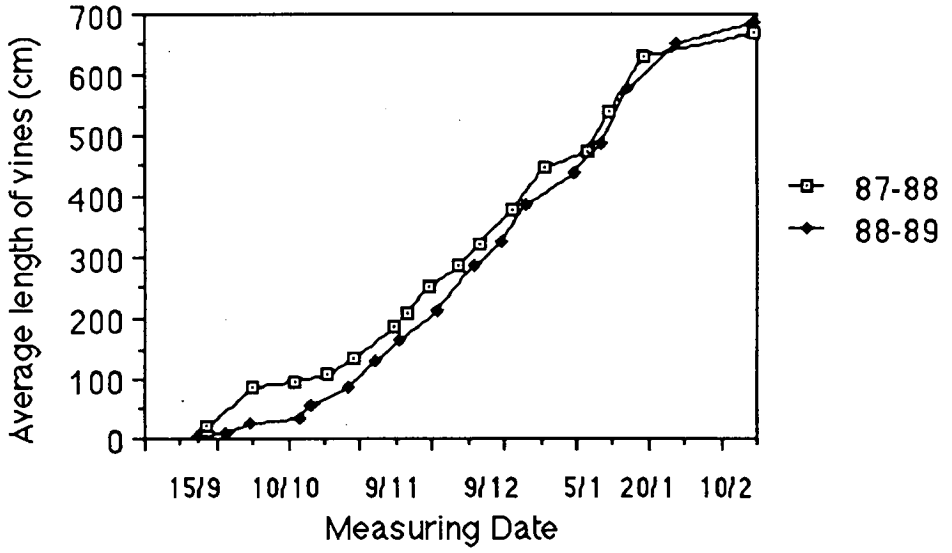
Fig. 5.27. Population changes of adult female mites on whole plants of commercially sprayed crops in seasons 1987-88 and 1988-89.



*: Spray 1 was applied on December 9, 1987, and spray 2 January 27, 1988. Spray 3 was applied on December 15, 1988.

The growth of hop plants in the two seasons is shown in Fig. 5.28.. Obviously, crops started growing earlier, about two weeks, and grew faster in 1987-88 than in 1988-89, though eventually they all achieved the normal height, 650-700 cm.

Fig. 5.28. The growth of hop plants in two seasons, 1987-88 and 1988-89.



There was a significant difference in the growth of mite populations in the two years, and this, in turn, resulted in different applications of miticides. Before the first application of miticides, i.e., early stages in the season, in 1987-88, populations of adult female mites were approximately the same as for all other treatments (Table 5.6.). This was found in the year of 1988-89 as well. However, following the significant suppression of mite populations by the application of miticides, changes occurred, not only in the densities of mite populations, but also in the stage composition of mite populations (Table 5.6.).

Table 5.6. Comparisons of mite densities and the stage composition for three treatments (C-S, U-C and P-P) at various time in 1987-88.

Height	Treatment	Σmites/leaf	Nos. A/leaf	A%	LN%	E%
			Sampling date			
			November 5, 1987			
0-90 cm	C-S	15.9	1.1	6.9	4.0	89.1
	U-C	10.5	1.53	15.3	0	84.7
	P-P	16.5	1.67	12.7	2.1	85.3
			November 18, 1987			
0-90 cm	C-S	90.91	3.1	3.4	22.4	74.2
	U-C	41.1	2.38	2.9	28.3	68.8
	P-P	90.0	4.72	2.8	29.1	68.1
			January 17, 1988			
Whole	C-S	350.1	11.2	3.2	35.8	61
plants	U-C	889.2	19.6	2.2	50.6	47.2
	P-P	687.8	15.1	2.2	51.3	46.5
			February 14, 1988			
Whole	C-S	182.3	6.2	3.4	25.0	71.6
plants	U-C	811.75	28.4	3.5	48.5	48.0
Whole			March 3, 1988			
plants	C-S	174.3	11.4	6.4	39.1	54.5
Whole			March 10, 1988			
plants	P-P	5.76	0.4	6.1	63.5	30.4
Whole			March 22, 1988			
plants	U-C	90.9	13.4	14.7	71.6	13.7

5.4. DISCUSSION

5.4.1. Lime-sulphur and Summer-oil as Miticides in Controlling TSSM on Hops

Undoubtly, these two materials were demonstrated to effectively suppress the population growth of TSSM on hops. It is known that lime-sulphur kills all active stages of spider mites, while petroleum oils kill both eggs and all active stages (Cranham and Helle 1985). In the present study, it was observed that the sprays of summer-oil caused higher immediate mortality to populations of TSSM than the sprays of lime-sulphur, and consequently kept mite populations lower for longer time and retarded the upwards dispersion of TSSM on hops. Therefore Summer-oil resulted in better control of TSSM on hops. As oils act through a physical mode, no mites have developed resistance to them, and there is no residue problem to the crop. Furthermore, they are not as harmful to beneficial natural enemies as the traditional insecticides and so are highly compatible with biological control methods (Cox and Atkins 1979). From this study, it has been demonstrated that oil sprays are effective against TSSM on hops. Thus, it can be suggested that summer-oil be used to control TSSM on hops as a substitute to the ordinary miticides.

The first sprays of lime-sulphur and summer-oil, which caused little phytotoxicity/leaf burn when the hops were less than two meter in height, proved that the recommended concentrations were adequate to apply to the early stages of hop development. However, at the time of the second and third sprays, the concentrations, which were the same for all the three sprays, could have been higher, for the hop plants were in a more developed and a 'hardened' condition, and therefore could be more

tolerant to the possible phytotoxicity and fairly high mite densities.

As to the timing of sprays, it appeared that three weeks was the maximum interval between sprays in the early stages of mite development. However, the third spray, applied more than seven weeks after the second, did reduce populations of TSSM. In fact, as the mortality to TSSM was not a hundred percent, it would be ideal to spray more than once in early season, before the formation of hop burrs, to prevent the build up of mite populations later in the season. From the experience and the results of the present study, the time interval between sprays should not exceed three weeks and this is also in agreement with the finding by Bartlett (1968) that the maximum period of toxicity retention was three weeks for light-medium grade oil and four weeks for lime-sulphur. However, this is in contrast to the result from Parker (1913) who found that when using lime-sulphur, the re-sprays must be applied seven or ten days later. This difference in the retention period of lime-sulphur is probably caused by the different content of the active constituent, polysulphides, in the lime-sulphur solutions.

It is suggested on available evidence that insect populations do respond to severe mortalities, such as those caused by the application of various pesticides, by rapidly increased birth and survival rates to compensate for the mortality and subsequently a resurgence of a population should be expected after chemical sprays (Price 1975). In this study, a similar phenomenon was observed (Figs. 5.3.b., 5.4., 5.5., 5.8. and 5.9.).

5.4.2. The Practicability of Natural Enemies in Controlling TSSM on Hops

It is evident that *Phytoseiulus persimilis* checked the rapid build up of

TSSM populations and eventually eliminated the prey on the trial plants. Although the release was made on a small scale, it proved to be effective. However, as this predator cannot survive the cold winter conditions of Tasmania, the predator has to be reintroduced every year. Consequently, this will certainly increase the expenses in purchasing or culturing and handling the predator and thus make it virtually impracticable to control TSSM by employing this predator before this mite becomes fully adapted to the climate in Tasmania through laboratory or glasshouse breeding.

The native predatory mite, *Amblyseius longispinosus*, was obviously not efficient enough on its own to control TSSM on hops, for it did not become active early enough after overwintering, nor were there enough individuals to suppress the populations of TSSM. However, as it is a native predator, it is suspected from observations that this mite could play an important role if combined with other control measures, such as cultural activities, and the application of chemicals less harmful to predators. More basic knowledge of its biology and ecology is required before further consideration.

The effect of *Stethorus* sp. on TSSM populations was even less significant than that of *Amblyseius longispinosus*, for the reason of its late appearance and too few individuals.

5.4.3. The Vertical Dispersion and Stage Composition of TSSM on Hops

It is very important to understand the exact location of TSSM on hops at different times in the season in order to make the spray of miticides more effective. However the vertical dispersion of TSSM on hops has received little attention so far. Sites and Cone (1985) found that TSSM were initially confined to the lower half of the plants from the initiation of plant growth,

but by early- to mid- August most of the mites were on the upper half of the plants. The results from this study showed similar sequence of TSSM vertical dispersion. That is, as the teneral female mites kept moving upwards as the hop vine extended in length, the mites gradually occupied the plant from lower to upper regions. However there were some variations in the dispersion pattern of the mite stages. For instance, in Fig. 5.8., for the date of January 17, the largest proportion of adult females was in the 3.6-5.5 m height range (the upper part), while the largest proportion of larvae and nymphs was in the next lower range 2.7-3.6 m Variation of egg numbers was more often associated with the proportion of adult females. The findings of the vertical dispersion pattern of TSSM on hops will certainly provide helpful knowledge for sampling mites so as to enable the grower or researcher to obtain more precise information of the pest. Therefore, when a spray is necessary, such information will help to direct the spray towards those regions with highest densities of TSSM.

Knowledge of stage composition of TSSM is also of importance, for it is an indication of the status of the mite population which will enable farmers or researchers to predict the developmental trend of the population or the intensity of infestation of mite populations. Different mite stages play various roles in the development of mite populations and the destruction of the host plants. Apparently a mite population with a high proportion of eggs, low proportion of larvae and nymphs is not making and will not damage plants in a few days, while a population with a high proportion of larvae and nymphs and a low proportion of eggs is damaging and will be still damaging the plant for the next few days. Thus the intensity of infestation is reflected not only by the density of mites which is obviously of primary importance, but also by the composition of the mite population. As the proportion of adult female mites is always very

low, usually less than 5%, it does not normally cause much damage to plants. It is believed that it is the group of larvae and nymphs which causes most of the damages to hop plants. Thus, the size of this group would actually reflect the feeding pressure rather precisely. Therefore the best opportunity of applying control measures, such as chemical sprays, would be the time when there are high proportion of eggs and relatively low proportion of larvae and nymphs.

Obviously, the stage composition of mite populations varied at different times in the growing season. Even though the mite densities were at the same level, there still appeared a significant difference in the composition of the populations (Table 5.6.). For instance, the mite density of the commercial crop was 91 mites/leaf on November 18, 1987, with 3.4% adult females, 22.4% larvae plus nymphs and 74.2% eggs in the population; and on March 22, 1988, there were again 91 mites/leaf on the untreated crop, while the population composition was 14.7% adult females, 71.6% larvae plus nymphs and 13.7% eggs. This strongly suggests that there is a self-regulating mechanism in mite populations enabling the mite to adjust population structure with the changes in the natural environment. In early season, when conditions are favourable to mite development, the majority of the population are eggs, implying a rapid increase of the total population in the near future. In late summer and early autumn, when conditions are becoming unfavourable, the majority of the population consists of larvae and nymphs, clearly indicating a termination of egg laying and the transition to the overwintering stage, i.e., adult females.

Carey (1982) proposed a stage distribution for TSSM as 66% eggs, 26% immatures and 8% adults. However the results from the present study show some disagreement with that proposed by Carey. This is caused

probably due to the fact that results from the present study were percentages calculated simply from the original counting rather than through a series of analyses of life history with mathematical modelling. Nevertheless, from the present research, it is adequate to propose an empirical critical stage distribution for control measures as 30% the group of larvae plus nymphs, and 60% eggs.

5.4.4. The Potential for Cultural Control of TSSM on Hops

From the results of observations and investigations in hop fields for two consecutive years it was understood that ploughing and sprinkler irrigation of the hop field are the most effective and promising cultural factors which have the potential for inclusion into a programme for controlling TSSM in hops.

Nuber (1961), based on the study of overwintering of TSSM in hop gardens, recommended that a thorough winter ploughing should be carried out in order to bury all the leaves under the ground so that the mites would die in the soil. However, as most of the overwintering TSSM were found inside dead shoots and twigs around the rootstocks, for normal ploughing, which is one of the usual cultural practices in the district carried out usually in the early to middle or late winter and cannot get very close to the rootstocks and therefore has little effect on the overwintering mites. From this investigation, it is evident that at the time of ploughing it is important to bury as many as overwintered mites on thistles which are scattered in the field and accessible by the normal ploughing. Undoubtedly, the best time for ploughing would be just before the majority of mites shifted onto small hop shoots, for this period is very short. Therefore it would be very important to monitor thistle leaves and

hop shoots and leaves closely and to plough the field very promptly. A proper ploughing in late winter (late August) or early spring (early September) would certainly diminish the numbers of overwintered female mites and therefore retard the subsequent rapid build up of the TSSM population.

The results of this investigation clearly demonstrate that the sprinkler irrigation systems do have a suppressing effect on mite densities, provided there is enough water to regularly spray the plant. It is well known that low temperatures and high relative humidities have an adverse effect on TSSM therefore outbreaks of TSSM do not usually occur in cold and wet weather. Parker (1913) found that irrigation of hop grounds did not control TSSM. However, Boudreaux (1958) found that newly hatched mites survive poorly in a moist atmosphere and explained that a high relative humidity inhibits water loss from mites through evaporation and this, in turn, slowed food intake and metabolism, for water-loss from the cuticle is necessary for optimal ingestion and utilization of food. Furthermore, it was found that the application of water using overhead sprinkler system have a depressing effect on the densities of Pacific mite (*Tetranychus pasificus*) in vineyards and was explained that the water removes the mites from the plants and, in addition, the decreased air temperature (being cooled by 3.9-5.5°C) and temperature of the foliage (being cooled by 8.3-13.9°C) and the high relative humidity (being raised by 10-20%) suppressed reproduction (Flaherty and Huffaker 1970, Gilbert *et al.* 1970, and Kinn *et al.* 1972). Tulisalo (1974) studied the effect of relative humidity and direct contact with water under laboratory conditions and found that conditions of constant high relative humidity led to the production of fewer eggs at a lower rate, and to a shorter longevity for egg-laying females than

a constant low relative humidity in TSSM. He pointed out that the mortality caused by watering and spraying is due not so much to relative humidity as to the suffocating effect of direct contact with water and that the spraying of water, a physical method, offers "new" possibilities for the control of mites.

Therefore, it is promising that there are links in the cultivation system which provide possibilities to control TSSM on hops without extensive use of destructive chemicals.

5.4.5. The Influence of Climate on Mite Populations and Hop Plant Growth

The differences in the initial development of mite populations (Fig. 5.27.) and the growth of hop plants (Fig. 5.28.) strongly suggest that climatic factors play very important role in the development of both TSSM and hops. In the year of 1987-88, two applications of miticides were made in order to suppress mite densities. While in 1988-89, only one application of miticides was made. However, since the growth of hop plants, in particular the early stages, varied with the climatic conditions, it is suspected that the various response of mite populations in the two years may be related to the conditions of the host plants as well. Therefore, the climate changes, particularly the changes in late winter and early spring and the growth conditions of plants, should be closely monitored in order to obtain more and precise information for the future control measures. Further knowledge of the interactions between climate, plant growth and mite population development would be of great value in establishing an IPM for TSSM on hops.

CHAPTER SIX

THE IMPACT OF TSSM FEEDING ON HOP PRODUCTION

CHAPTER 6 THE IMPACT OF TSSM FEEDING ON HOP PRODUCTION

6.1. INTRODUCTION

TSSM was recorded as a serious pest on hops as early as 1905 in California, when leaves from 30 per cent of 34 ha. hops were blown away and the bale consisted of mainly trash (Parker 1913). When severely infested, hop leaves first turn yellow, then dry and may fall to the ground; while cones become dry, red and so brittle that they cannot be picked (Parker 1913). Although both quality and yield of hops can be greatly reduced and total losses can occur (Cranham 1985), no assessment of actual damage-yield relationship has been made for hop farms. In order to obtain basic information for the establishment of an economic injury level and ultimately an integrated control programme for TSSM on hops, the loss of hop yield caused by TSSM feeding was evaluated quantitatively in the field for two consecutive seasons, 1987-88 and 1988-89.

6.2. MATERIALS AND METHODS

6.2.1. 1987-88 Studies

Experiments were carried out in the experimental plot as described in 5.2.1.. There were seven treatments altogether and they were designated as : 1) C-S - receiving commercial sprays (applications of a single spray of either a mixture of Omite and Apollo, or Omite only were applied on December 9, 1987 and January 27, 1988, respectively); 2) P-P - receiving *Phytoseiulus persimilis* only; 3) U-C - untreated control; 4) 2-O - receiving two

receiving two applications of Summer-oil only; 5) 3-O - receiving three applications of Summer-oil only; 6) 2-S - receiving two applications of Lime-sulphur only; and 7) 3-S - receiving three applications of lime-sulphur only. Mite populations were sampled, on the basis of individual plants, throughout the season as mentioned in 5.2.1.. During harvest time, all study plants were cut from the string and were placed in separate synthetic Stock Feed bags at a rate of all vines from one string per bag. Field harvest was completed on March 27-28, 1988. To reduce variation, equal numbers of plants from every treatment were cut. All the harvested vines were brought to the laboratory and stored at 2°C before cones were hand picked over the next five days. The number of vines attached to each string was recorded and cones from these vines were picked and weighed on a Mettler PC 4400 balance as one sample. Therefore, the mean wet weight of cones per vine was easily obtained by dividing the cone weight of one string with the numbers of vines attached on the string. A total of 94 strings of 34 plants, from seven treatments, were harvested and picked. The cones from each string were processed in the following way:

1). 50 cones were randomly chosen and divided into 6 portions, five with 5 cones, another with 25 cones (originally it was intended to weigh each of the 50 cones, however time restraints resulted in present procedures which allowed estimates based on 5 x 5 cones and 1 of 25);

2). the six portions were weighed separately with an analytical balance (Mettler H10T.) and the results were added together then divided by 50 to produce the mean wet weight per cone for the string;

3). the 50 cones were dried in one paper bag at a constant temperature of 60°C, for 48 hours in a Unitherm Drier (Birmingham and Blackburn Construction) , then equally divided into 5 portions, each with 10 cones; and

4). the five portions were weighed separately and the results summed up, then divided by 50 to give the mean dry weight per cone (an indication of cone size) for the string.

To obtain the number of cones per vine for every string, the mean wet weight of cones per vine was divided by the mean wet weight per cone. The mean dry weight of cones per vine was obtained by multiplying the number of cones per vine by the mean dry weight per cone.

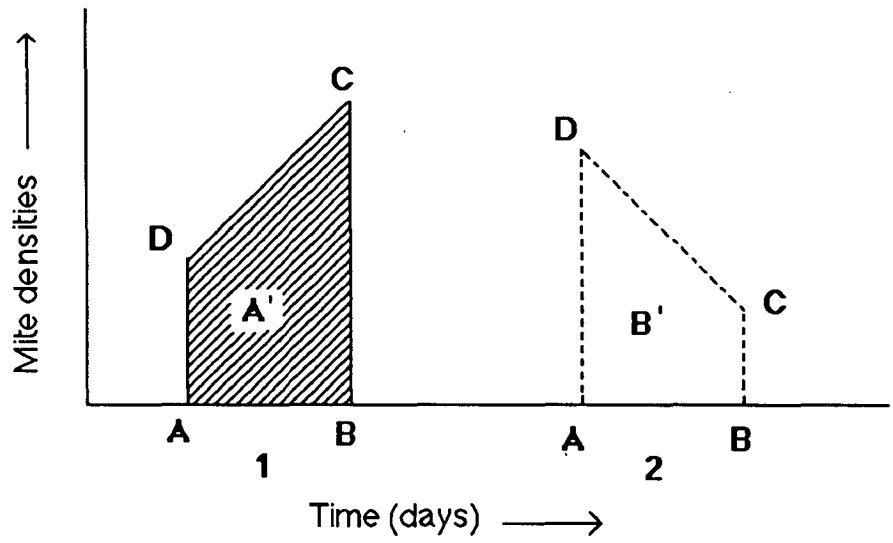
Consequently the five parameters obtained above, i.e., the mean wet weight of cones per vine, the mean dry weight of cones per vine, the mean number of cones per vine, the mean wet weight per cone and the mean dry weight per cone, were used in subsequent statistical analyses.

Dry yields obtained on the basis of per vine were averaged within individual plants to produce the mean dry yield per vine for all study plants in order to examine the relationship between hop yield and mite density which was monitored throughout the season on the basis of the number of adult female mites per leaf per study plant.

While the numbers of adult female mites per leaf were compared among treatments, accumulative mite-days, more correctly adult-female-mite-days (one adult-female-mite-day equivalent to one adult female mite feeding for one day) were converted by modifying the procedure described by Sevacherian *et al.* (1977) for the calculation of degree-days from max. and min. temperature data (Illustration 6.1.), so as to express not only the mite density, but also the infestation duration in mite-days. Although the adult

female-mite-days cannot exactly describe the degree of injury caused by mite feeding (for adult female mites only form a very small part in mite populations and the main feeding cohort is the group of larvae plus nymphs), it can still express, to some extent, the general difference of mite feeding pressure on hop plants among treatments.

Illustration 6.1. The calculation of mite-days.



Case **1** is an increasing mite population, and **2** decreasing one.

D is the mite density (number of mite per leaf) at time **A**, and **C** the density at time **B**. Therefore the area of **A'** and **B'** will be the mite-days for case **1** and **2**, respectively.

In either case, there is:

$$\text{area } A' \text{ (or } B') = \frac{(AD + BC)\,AB}{2}$$

Thus, mite-days = ((**D** + **C**) * days between **A** and **B**) + 2

6.2.2. 1988-89 Studies

The experimental plot was established in the middle of one commercial hop field and was three hop rows wide and 270 hop plants long. Originally it was planned to establish the seven treatments, however, as the season progressed, it was found that cultural activity and climatic variation (see page 195, **5.3.5.** for details), made it no longer necessary to continue the proposed experiment, as the numbers of TSSM were simply too low. Consequently, all the study plants were grouped into two lots, and one lot commercially sprayed (with a mixture of Omite and Apollo on December 14-16, 1988) and the other left unsprayed as untreated control. The mite populations of these two areas were monitored throughout the season. At harvest time, cones were collected in the same way as described above. All the post-harvesting processing procedures were as those employed in 1987-88. The same parameters and statistical methods were employed. Altogether, 74 strings from 26 plants were processed.

No attempt was made to quantify the effect of TSSM infestation on hop cone quality other than the cone weight (i.e. the size of cone).

6.2.3. Statistical Analyses

Simple linear regression (Zar 1984, pp. 261-289) and one way ANOV (Zar 1984, pp. 162-167) were carried out when comparing the measured variables between treatments. The calculations were completed using Macintosh software StatView^{TM} SE+. In addition, Newman-Keuls multiple range test (Zar 1984, pp. 186-191) and Dunnett's test for comparing one mean to other means (Zar 1984, pp. 194-195) were applied.

6.3. OBSERVATIONS AND RESULTS

6.3.1. 1987-88 Studies

6.3.1.1. The general appearance of the hop plants

The untreated control plants were heavily infested with TSSM throughout the season. It was found that the elongation of vines was not obviously retarded on these plants. However, there were fewer side-branches and leaves on the upper half of the plants (there is no side-branch on the lower half for normal hop plants), resulting in a much smaller and sparser canopy. The leaves of these plants were distinctly yellowish and the numbers of leaves were much fewer than the normal plants in the middle of the season and it was expected that these plants would be completely ruined. However, as the season progressed, the vines still achieved normal height and burrs and cones were formed and later ripened (Plate 10.). For plants receiving *Phytoseiulus persimilis*, some of their leaves were slightly yellowish when the predators were released. Two to three weeks after the release the plants had regained a normal appearance in terms of the number of leaves and side-branches on the upper half of the plant, especially in the canopy, and the green colouration of leaves. At harvest time, these plants were no different than the normal commercially sprayed plants (Plates 11. & 12.).

For the other treatments, plant appearance varied widely between the untreated control and commercial crops.

Plate 10. Untreated control.

Plate 11. *Phytoseiulus persimilis* released.

Plate 12. Commercially sprayed crop.

Note: Photos on this page were taken ten days before harvesting.

6.3.1.2. Aspects of cone production

The records of mean wet weight of cones per vine for the seven treatments is presented in Appendix 6.1.. The aspects of cone production in 1987-88 is summarized in Table 6.1.. It was found that there were significant differences among the mean wet weight of cones per vine for the seven treatments, i.e., the means were not all equal ($p < 0.5$)(Appendix 6.2. & Fig. 6.1.). The test of Newman-Keuls multiple comparison revealed that the mean wet weight of cones per vine from U-C was equal to that from 2-S ($p < 0.5$), but not to the other mean values (p's > 0.5) ((Appendix 6.3.). Obviously, the low mean wet weight of cones per vine from untreated control was caused mainly by the heavy infestation of TSSM.

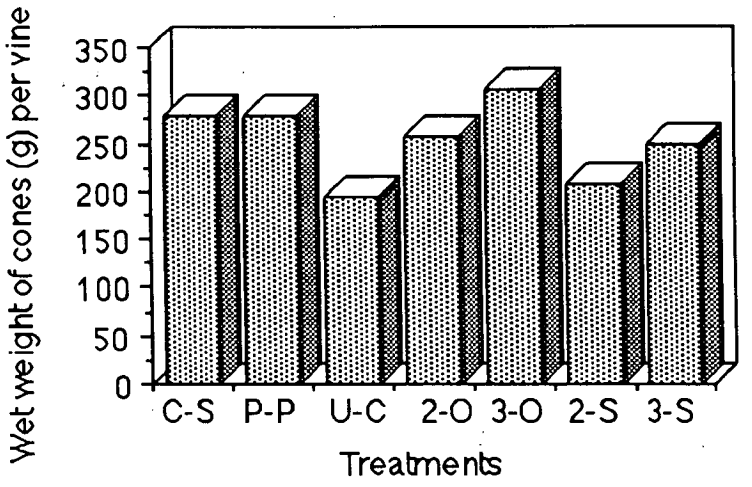
Treatment 3-O produced 306.12 g/vine, the highest mean wet weight of cones per vine, followed by P-P (278.93), C-S (278.62), 2-O (255.72), 3-S (249.19), 2-S (206.79), and the lowest U-C (194.41).

Table 6.1. Summary of the cone production in 1987-88.

	Parameters*				
Treatment	1 (g)	2 (g)	3 (g)	4	5 (g)
C-S	278.62	0.4278	0.1206	659	78.47
P-P	278.93	0.5188	0.1393	540	75.13
U-C	194.41	0.4632	0.1295	423	54.97
2-O	255.72	0.5322	0.1532	490	72.94
3-O	306.12	0.5884	0.1633	534	87.13
2-S	206.79	0.4923	0.1322	418	55.53
3-S	249.19	0.4922	0.1472	516	73.87

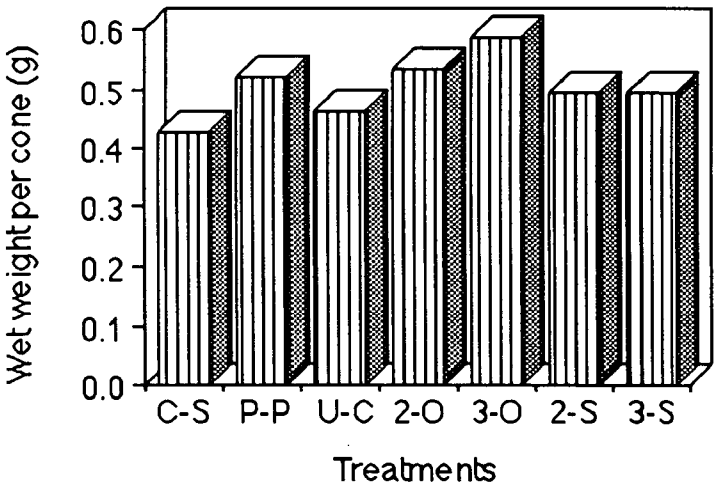
*: 1 = mean wet weights of cones per vine; 2 = mean wet weights per cone; 3 = mean dry weights per cone; 4 = the numbers of cones per vine; 5 = mean dry weights of cones per vine.

Fig. 6. 1. Average wet weight of cones per vine from treatments.



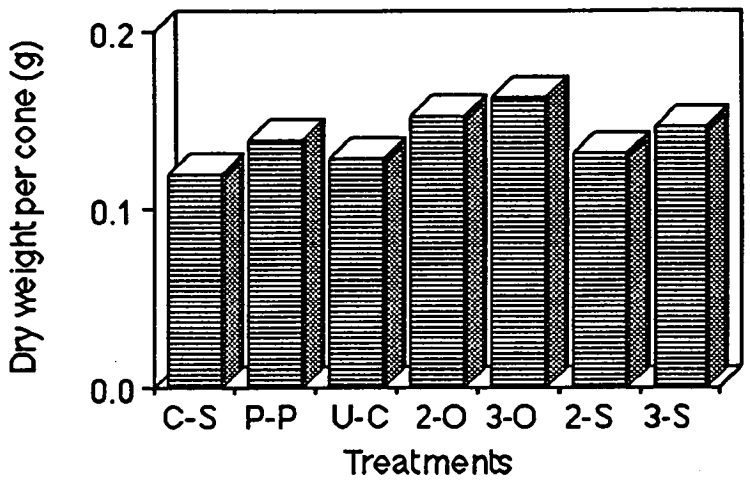
Appendix 6.4. presents the mean wet weights per cone from strings of the seven treatments. This parameter gives a reasonable appreciation of the size of hop cones. The largest cones were 0.5884 g from 3-O, followed by 2-O (0.5322 g), P-P (0.5188), 2-S (0.4923), 3-S (0.4922), U-C (0.4632) and C-S (0.4278). One-way ANOV showed that the mean weights of single wet cones were significantly different ($p < 0.05$) for the seven treatments (Appendix 6.5. & Fig. 6.2.). Further tests indicated that the mean wet weight per cone of the C-S was not less than that of the U-C ($p < 0.05$), but less than those of the other treatments (p's > 0.05); and that the mean wet weight per cone of U-C was not less than those of 2-S, 3-S, and C-S (p's <0.05), but significantly less than those of P-P, 2-O and 3-O (p's > 0.05) (Appendix 6.6.).

Fig. 6. 2. Mean wet weight per cone from treatments.



After drying, the mean weight per cone from the seven treatments showed some differences, with the largest dry cone from 3-S (0.1633 g), which was followed by 2-O (0.1532), 3-S (0.1472), P-P (0.1393), 2-S (0.1322), U-C (0.1295), and the smallest C-S (0.1206). Statistical analysis revealed that the mean dry weight per cone of the C-S was not smaller than those of 2-S and U-C (p's < 0.05), but smaller than those of the other treatments (p's > 0.05); and that the mean dry weight per cone of U-C was not smaller than those of P-P, 2-S and C-S (p's < 0.05), but was significantly smaller than those of 3-S, 2-O and 3-O (p's > 0.05) (Appendices 6.7., 8.&9., Fig. 6.3.).

Fig. 6. 3. Mean dry weight per cone from treatments.



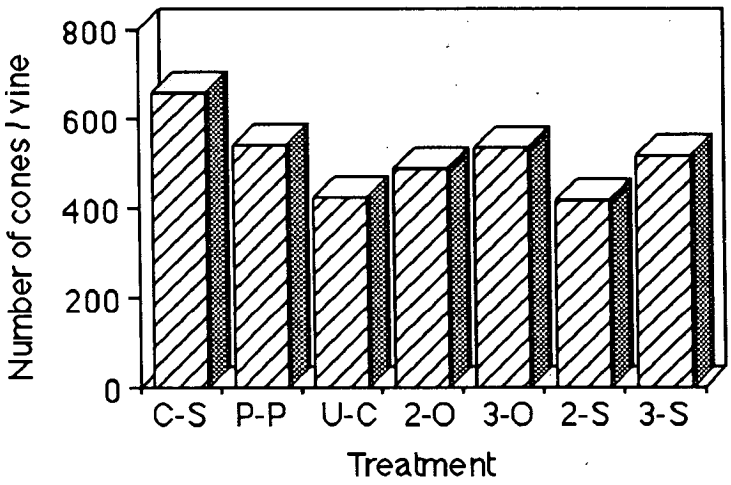
Moisture contents of individual cone for the seven treatments were not equal. (Table 6.2.).

Table 6.2. Simple linear regression analysis between the dry and wet cone weights: Y (dry weight) = b x (wet weight).

Treatments	b	1-b	n	r^2	F	p
C-S	0.2803	0.7197	15	0.73	34.53	< 0.000
P-P	0.2684	0.7316	17	0.66	28.61	< 0.000
U-C	0.2784	0.7216	21	0.52	20.74	< 0.000
2-O	0.2885	0.7115	12	0.73	26.91	< 0.000
3-O	0.2775	0.7225	9	0.89	56.66	< 0.000
2-S	0.2693	0.7307	9	0.94	104.21	< 0.000
3-S	0.2988	0.7012	11	0.69	19.67	= 0.002

The numbers of cones per vine from the various treatments are presented in Appendix 6.11.. It was found that the mean numbers of cones per vine were not all equal for the treatments (Appendix 6.12. and Fig. 6.4.); that the mean number of cones per vine from C-S (659) was the greatest in all treatments (p's > 0.05), followed by P-P (540), 3-O (534), 3-S (516), 2-O (490), U-C (423) and the smallest 2-S (418); and that the mean number of cones per vine of U-C was not less than those of 2-S and 2-O (p's < 0.05), but less than those of C-S, P-P, 3-O and 3-S (p's > 0.05) (Appendix 6.13.).

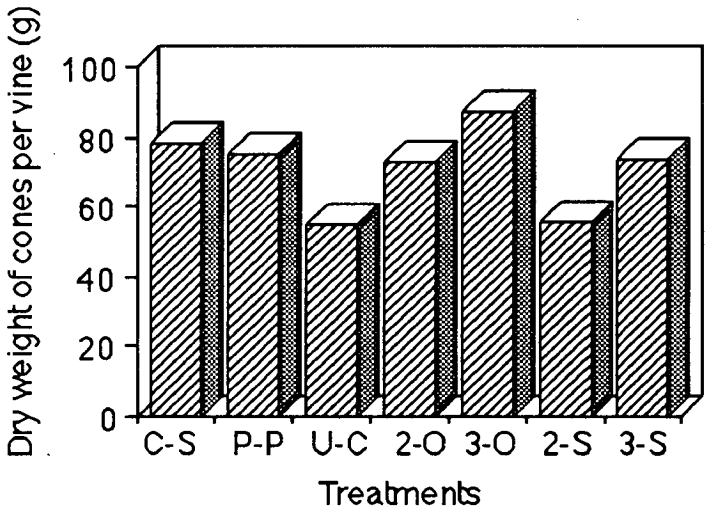
Fig. 6.4. Mean numbers of cone per vine for treatments.



The mean dry weights of cones per vine from the seven treatments were not equal (p < 0.05), the maximum being 87.13 g/vine from 3-O, which was followed by C-S (78.47 g), P-P (75.13 g), 3-S (73.87 g), 2-O (72.94 g)

and 2-S (55.53 g), and the minimum 54.97 g/vine from U-C (Appendices 6. 14. & 15., Fig. 6.5.). It was found that the mean dry weight of cones per vine of C-S was only greater than those of U-C and 2-S (p's > 0.05), both of which were equal to each other (p < 0.05) but not to those of the remaining treatments (p's > 0.05); and that the mean dry weight of cones per vine of U-C was not less than that of 2-S (p < 0.05), but was significantly less than those of the other treatments (p's > 0.05) (Appendices 6.16. and 17.).

Fig. 6. 5. Mean dry weight of cones per vine from treatments.



6.3.1.3. Production losses

In the comparison to the conventional, commercially sprayed crop, a reduction of production in untreated control was found. The mean number of cones per vine was reduced by approximately 36% and the mean dry weight of cones per vine by about 30%. Simple linear regression

revealed that the mean dry and wet weight of cones per vine, were determined, in a large part, by the number of cones on the vine (Table 6.3); and that nearly 70% of the variation in mean dry cone weight per vine could be explained by the variation in number of cones on vines ($r^2 = 0.67$) (Fig. 6.6.). It was also found that there was a significant trend to indicate that as mean dry weight per cone increased the numbers of cones from that vine decreased (Fig.6.7.); and that the increase of mean dry cone weight per vine was in direct proportion to that of the mean dry weight per cone (Fig. 6.8.). Therefore, the variation in mean dry weight of cones per vine of approximately 97% ($r^2 = 0.967$) can be best explained by the additive effect of the number of cones and the dry weight of each cone on the vine (Table 6.3.).

Table 6.3. Simple linear regression analysis among yields, cone weights and the numbers of cones on each vine.

Y	X	a	b	n	r^2	F	p
Wet W./vine	Wet W./cone	105.94	289.75	94	0.103	10.60	0.0016
Dry W./vine	Dry W./cone	29.09	295.58	94	0.126	13.22	0.0005
Wet W./vine	Nos. of cones	47.50	0.395	94	0.674	190.3	0.0001
Dry W./vine	Nos. of cones	13.39	0.111	94	0.666	183.7	0.0001
Nos. of cones	Wet W./cone	740.3	-463.19	94	0.061	5.975	0.0164
Nos. of cones	Dry W./cone	699.07	-1357.05	94	0.049	4.714	0.0325
Dry W./vine (Multiple)	Nos. of cones (X_1) and Dry W./cone (X_2)	-60.10	0.128 468.72	94	0.967	1324.5	0.0001

Fig. 6.6. The relationship between mean dry weight of cones and the numbers of cones per vine.

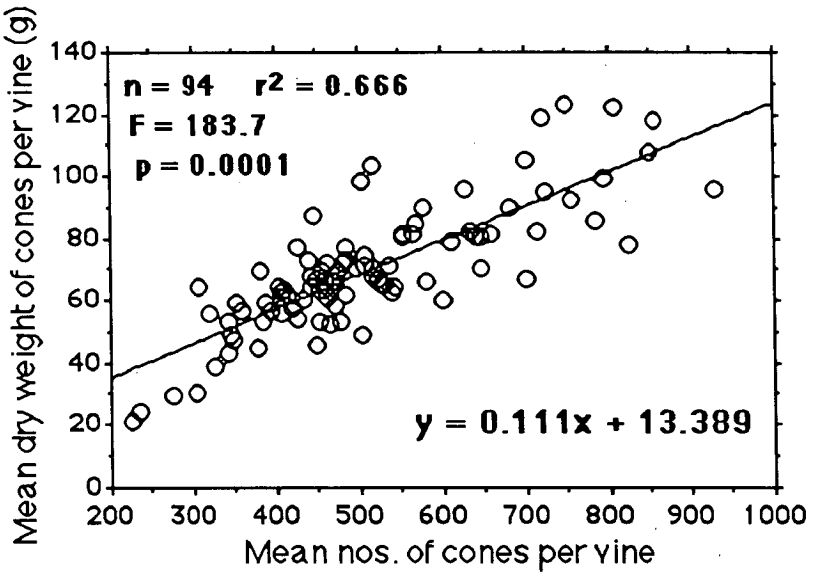


Fig. 6.7. The relationship between the numbers of cones per vine and the mean dry weight per cone.

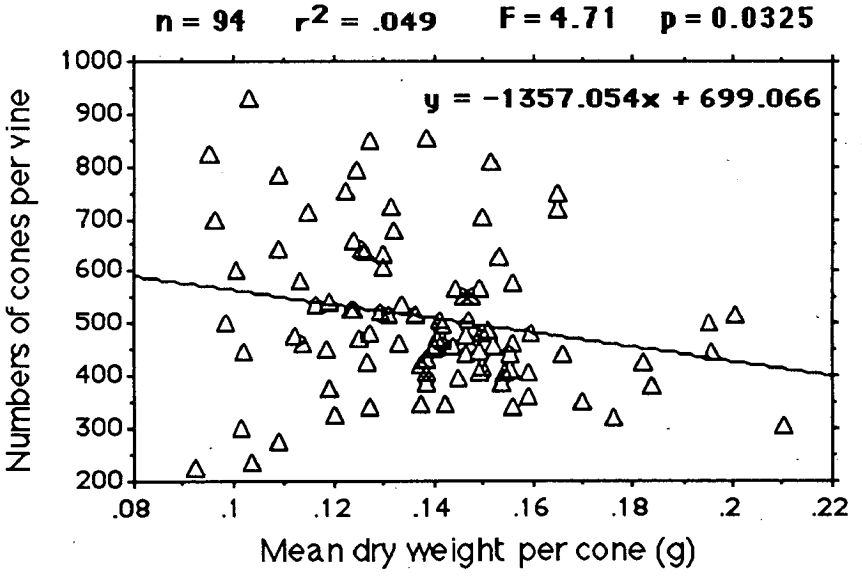
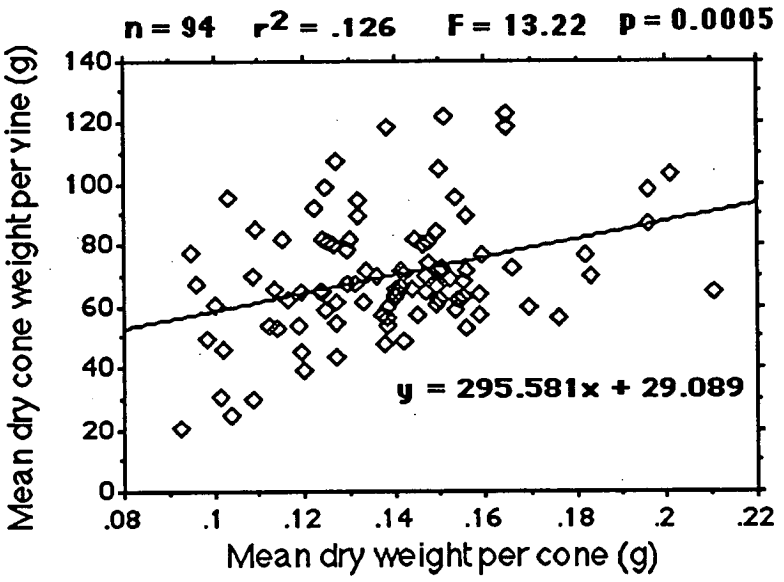


Fig. 6.8. The relationship between mean dry weight of cones per vine and the mean dry weight per cone.



6.3.2. 1988-89 Studies

Values of the five parameters designated above (c.f. Page 216, Paragraph 3) are given in Appendix 6.18.. In this season, plants in the commercially sprayed and unsprayed crops did not exhibit any substantial differences in respect to general appearance. All the five parameters were compared for only these two treatments. Although the mean wet weight of cones per vine from the two group were statistically equal to each other ($p > 0.05$) (Appendix 6.19.), there were differences between commercial crop (484.25 g/vine) and untreated crop (447.53 g/vine).

Appendix 6.20. indicates that the mean wet weights of cones were almost the same for the two groups ($p = 0.9007 >>> 0.05$), 0.488 g for commercial crop and 0.490 g for the untreated crop. Similarly, the mean

dry weights per cone were equal for the two groups, 0.139 g for commercial crop and 0.135 g for the untreated group ($p > 0.05$)(Appendix 6.21.). The mean number of cones per vine was 1008 for the commercial crop and 925 for untreated crop, but this difference was not statistically different ($p > 0.05$) (Appendix 6.22.). However, the most important aspect in production, the mean dry cone weights per vine of the two groups were different ($p = 0.0435 < 0.05$), with 138.24 g/vine for the commercial crop and 123.89 g/vine for the untreated crop, a 8% reduction (Appendix 6.23.). The graphic comparison of the five parameters for the two groups are given in Fig. 6.9..

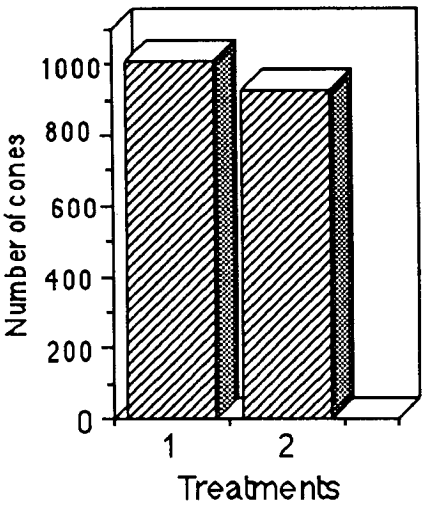
Although wet/fresh cone weights of the two groups were not statistically different, the mean dry weight of cones per vine were significantly different. Therefore the cone harvest from the commercially sprayed crop was superior to those of the untreated crop by producing more hops. The loss of cones in the untreated crop was approximately 10% (mean dry weight of cones per vine).

The ultimate production, the mean dry weight of cones per vine, was found to be significantly related to the number of cones on the vine (Fig. 6.10.), with 85% ($r^2 = 0.84$) variation in dry yield being explained by the variation in the numbers of cones.

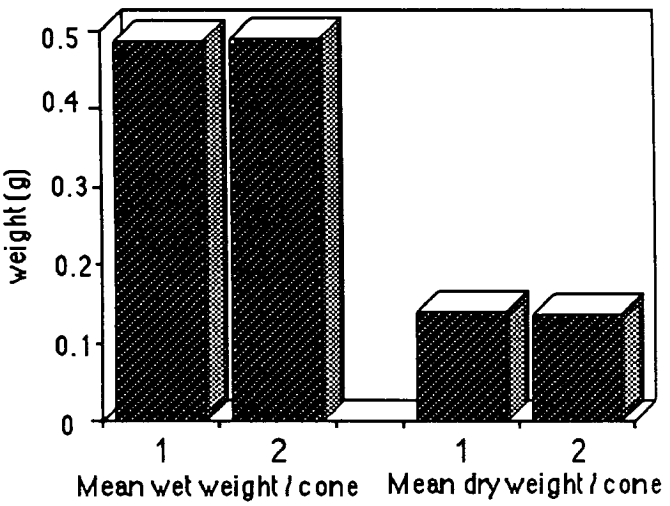
While it is significant that the number of cones per vine was inversely proportional to the mean dry weight per cone ($p = 0.0001$) (Fig. 6.11.), the mean dry weight of cones per vine was not related to the mean dry weight of each cone ($p = 0.3745$) (Fig. 6.12.). Again, the integrative effect of the number of cones per vine and the mean dry weight of each cone explained 98.7% ($r^2 = 0.987$) variation in ultimate production, the mean dry cone weight per vine (Table 6.4.).

Fig. 6.9. The comparison of the five parameters between commercially sprayed crop (1) and non-sprayed crop (2).

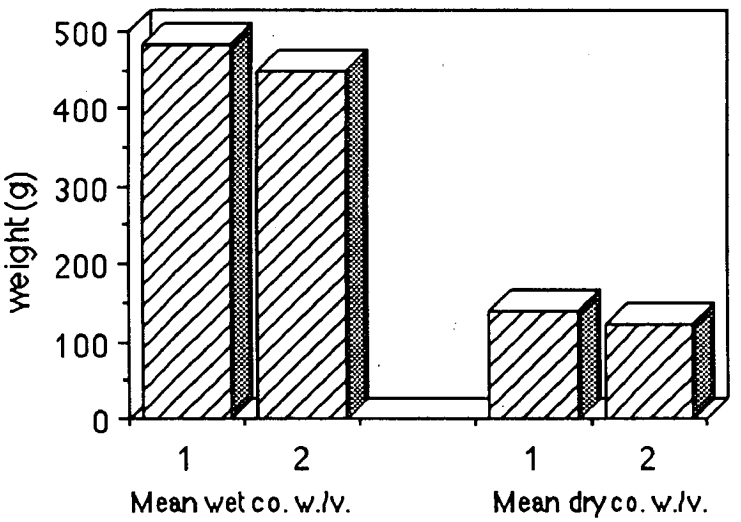
a. Nos. of cones /vine.



b. Mean weights of each cone.



c. cone weights on each vine.



*: **b.** and **c.** are so arranged to show the differences between the wet and dry weights.

Fig. 6.10. The relationship between mean dry weights of cones per vine and the numbers of cones per vine for the two groups in 1988-89.

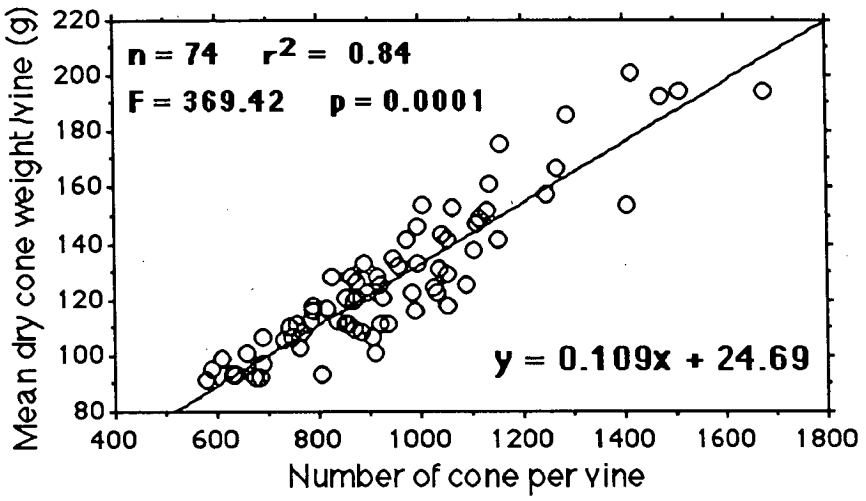


Fig. 6.11. The relationship of the numbers of cones per vine to the mean dry weights per cone.

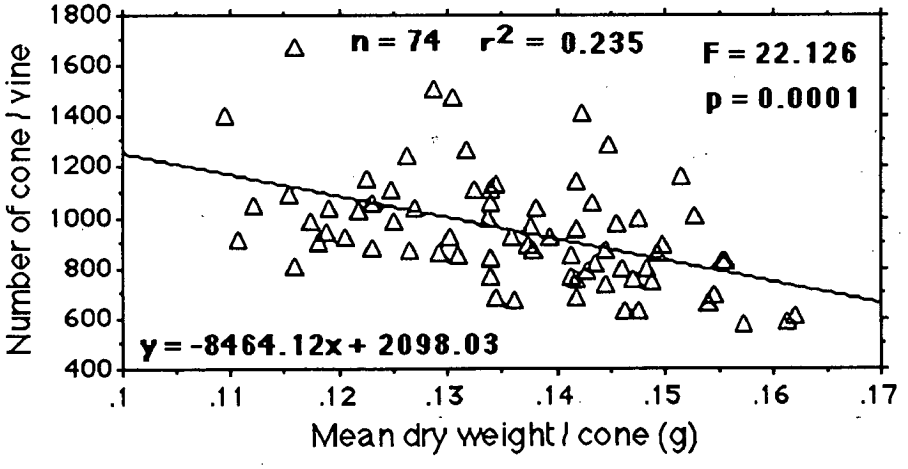


Fig. 6.12. The relationship between mean dry weights of cones per vine and mean dry weights of each cone.

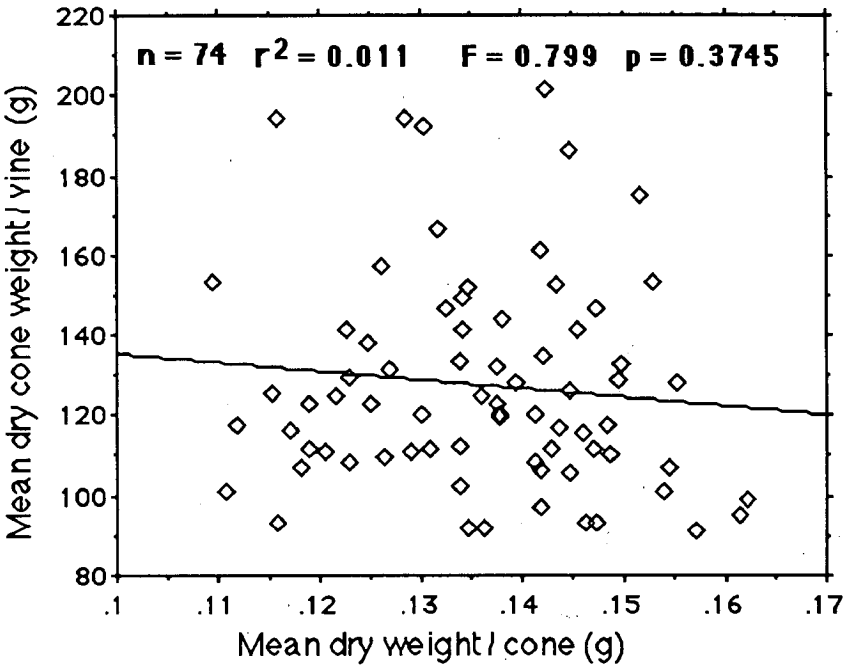


Table 6.4. Simple linear regression analysis of hop yields in 1988-89.

Y	X	a	b	n	r^2	F	p
Wet W./vine	Wet.W/cone	557.148	-205.83	74	0.013	0.952	0.3324
Dry W./vine	Dry W./cone	156.958	-217.162	74	0.011	0.799	0.3745
Wet W./vine	No. of cone	112.194	0.364	74	0.893	284.662	0.0001
Dry W./vine	No. of cone	24.69	0.109	74	0.837	369.42	0.0001
No. of cone	Wet W./cone	2099.41	-2359.52	74	0.285	28.722	0.0001
No. of cone	Dry W./cone	2098.03	-8464.12	74	0.235	22.126	0.0001
Dry W./vine (Multiple)	No. of cone (X_1) and Dry W./cone (X_2)	-124.487	0.134 918.276	74	0.987	2683.21	0.0001

6.3.3. The Effect of TSSM Feeding

From the results, TSSM feeding should be considered the main factor causing differences in production, for other relevant factors, such as climate, cultural activities, soil type, etc., were similar to all treatments. These effects were clearly shown in the two years of study. In year one (1987-88) conditions favoured mite feeding and population increase while in year 2 (1988-89) mite populations were suppressed. That is in year one it was essential that TSSM was controlled by multiple sprays while in year two, only one spray was required.

The number of adult female TSSM on different treatments throughout the season of 1987-88 are given in Table 6.5. It can be seen that prior to December 9, 1987, when the first commercial spray was applied, the mite densities were higher on the commercially sprayed (C-S) and predator released (P-P) plants than on other plants; and that from then until December 21, the mite populations reached the highest densities on untreated plants. Following establishment of the different treatments, some differences were detected during the period of intensive mite feeding on hop leaves. The commercial sprays gave excellent kill over all treated mite populations, therefore, from December 10, right after the first spray, until January 27, the day the second spray was applied, these crops only experienced a gradually increased feeding pressure which was virtually non-existent during the first two to three weeks but became prominent in mid-January. After the second spray, until February 14, mite feeding pressure was maintained at a low level. However, in the untreated crop, mite populations increased steadily and reached the highest levels on January 17, and were maintained at approximately the same level of feeding pressure until February 14.

On January 17, the feeding pressure from mites, mainly larvae plus nymphs, among treatments, was, from the highest to the lowest: U-C, 2-S, 2-O, 3-S, P-P, 3-O and C-S and by February 14, the order had changed to U-C, 3-S, 2-S, 2-O, 3-O and C-S. No sampling was made for P-P on February 14. However it was believed, from the observation, that the mite densities on P-P plants were lower than that of C-S plants.

A complete comparison of all stages of mites on leaves, sampled on January 17 and February 14, 1988, is presented in Table 6.6.. Obviously the mite density was very low on the commercial crop compared to the other treatments, and the proportion of larvae plus nymphs was also very low. The differences in the number of adult female mites, and the number of all stage s of mites did not directly reflect the actual feeding pressure imposed mainly by the larvae plus nymphs group.

For example, although the number of adult female mites on the untreated control (U-C) was 19.6 per leaf, well below that of treatments 2-O, 3-O, 2-S and 3-S, the number of larvae plus nymphs was 450 per leaf, which was followed by that of 2-S and 2-O. In contrast, on February 14, the number of adult females in U-C was 28.4 per leaf , being the highest among treatments and feeding pressure was also the highest with 394 larvae plus nymphs per leaf. All the mite populations decreased dramatically from January 17 to February 14, 1988, except that of the untreated control, with only a slight decrease in the numbers of all mite stages. After February 14, 1988, the mite populations in treatment C-S hardly changed thus the feeding pressure was maintained. However, the stage composition in C-S varied in such a way to exhibit a general downward trend in the mite population in keeping with the periodical climatic changes. For the treatment P-P, the effective predation by *Phytoseiulus persimilis* almost eliminated the mite

populations by March 10, indicating a rapid decline in feeding pressure. On March 22, 1988, a week or so before harvesting, the mite populations were very low on the untreated control plants but still maintained a considerable feeding pressure on the crop, higher than that, existed five weeks ago, on the commercially sprayed crop on February 14.

Table 6.5. The comparison of the populations changes of adult female mites for whole plants for the seven treatments.

Average numbers of adult females per leaf									
Treatment	Sampling Date (1987-88)								
	5/11	18/11	2/12	10/12	21/12	28/12	17/1	14/2	
C-S	1.1	3.1	12.6*c	-	-	3.8	11.2*c	6.2	11.4 (3/3)
P-P	1.67	4.72	11.31	20.45**		-	15.1	-	0.4 (10/3)
U-C	1.53	2.38	4.96	-	22.21	-	19.6	28.4	13.4 (22/3)
2-O	0.85*	0.34	2.81	-	10.53	-	26.1*	16.6	
3-O	1.68*	1.36	5.93*	-	11.94	-	23.5*	9.6	
2-S	1.11*	1.7	4.9	-	17.54	-	20.2*	15.9	
3-S	1.63*	2.18	6.18*	-	10.28	-	22.0*	20.4	

*c: Commercial spray applied shortly after that day;

**: *Phytoseiulus persimilis* released on that day;

*: Lime-sulphur or summer-oil applied shortly after that day;

-: Sampling did not occur.

Table 6.6. Number of mites per hop leaf on January 17, and February 14, 1988 for the seven treatments.

Treatment	ΣM/L	A/L	A%	LN/L	LN%	E/L	E%
			January 17, 1988				
C-S	350.1	11.2	3.2	125.4	35.8	213.6	61
P-P	687.78	15.1	2.2	352.8	51.3	319.8	46.5
U-C	889.22	19.6	2.2	450	50.6	419.7	47.2
2-O	1010.1	26.1	2.58	431.3	42.75	552.2	54.67
3-O	982.22	23.5	2.39	334.5	34.06	624.2	63.55
2-S	1007.26	20.2	2.0	448.2	44.5	538.9	53.5
3-S	956.4	22.0	2.3	391.2	40.9	543.2	56.8
			February 14, 1988				
C-S	182.3	6.2	3.4	45.6	25.0	130.5	71.6
U-C	811.75	28.4	3.5	393.7	48.5	389.6	48.0
2-O	531.23	16.1	3.12	108.7	20.46	406.0	76.4
3-O	278.88	9.6	3.43	77.4	27.75	191.9	68.82
2-S	612.43	15.9	2.6	325.8	53.2	270.7	44.2
3-S	755.68	20.4	2.7	331.7	43.9	403.5	53.4
March 3 C-S	174.3	11.4	6.4	68.2	39.1	95.0	54.5
March 10 P-P	5.76	0.35	6.1	3.66	6.4	1.75	30.5
March 22 U-C	90.9	13.4	14.7	65.1	71.6	12.4	13.7

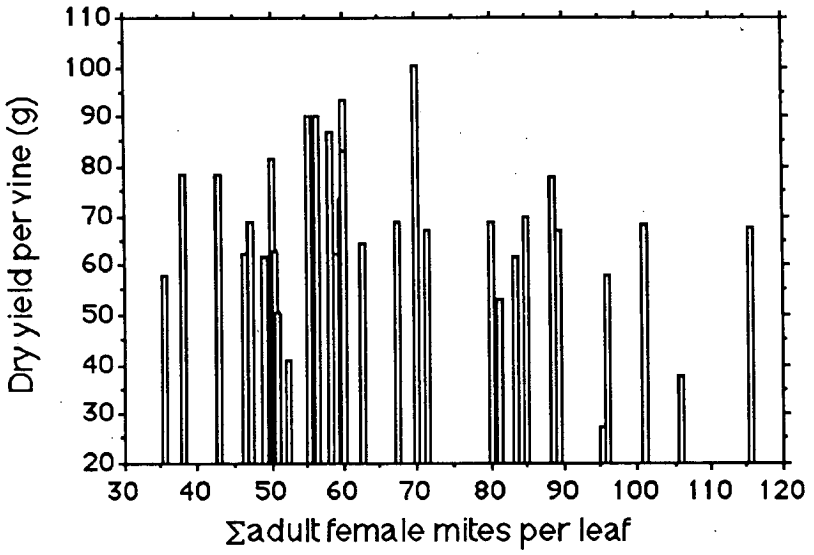
The number of adult female mites on hop leaves, in the season of 1988-89, for the two treatments, is shown in Table 6.7.. As mite population densities were very low, no attempts of studying the stage composition of them were made. Apparently, the difference in the numbers of mites occurred between December 15, 1988 and January 26, 1989.

Table. 6. 7. The number of adult female mites per leaf in 1988-89.

Sampling date	Com. crop	Untreated crop
20/11/88	0.47	0.41
1/12	0.94	0.69
15/12	spray	3.36
28/12	0.6	1.22
12/1/89	0.2	2.3
26/1	0.05	0.77
16/2	0.01	0.10

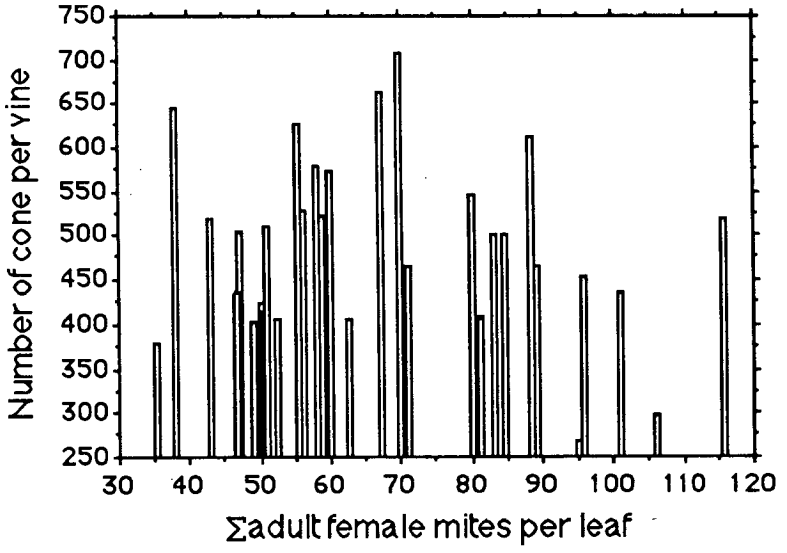
The relationship between the accumulative number of adult female mites per leaf of all study plants and the yield parameters of these plants in two seasons are shown in (a) Fig. 6.13. for the mean dry matter yield per vine; (b) Fig. 6.14. for the mean number of cones per vine and (c) Fig. 6.15. for the mean cone size. The relationship is rather complicated and obscure. No simple linear relationship (p's >> 0.05) or even quadratic relationships (p's >> 0.05) could be established. However, it is clear that plants with low mite numbers did not necessarily generate the highest yield, while those with high mite numbers did not necessarily produce the lowest yield.

Fig. 6.13. Plot of dry yield per vine for each plant against the accumulative number of adult female mites per leaf on the plant.



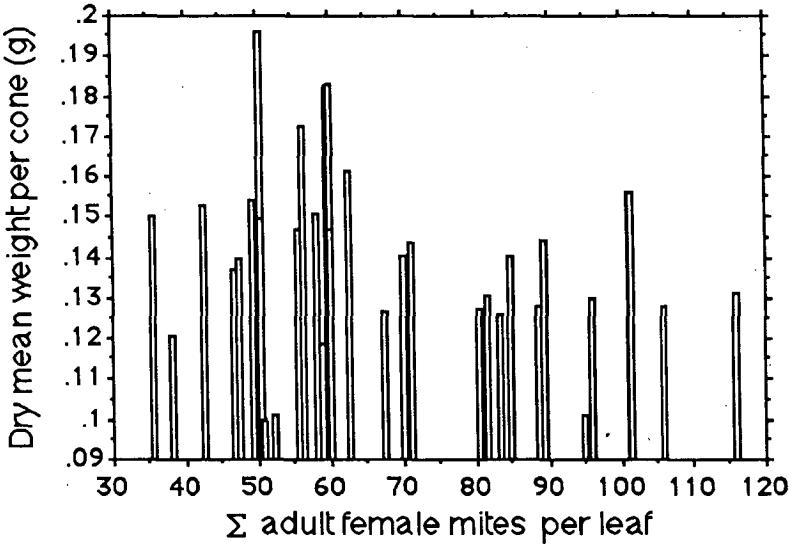
For simple linear regression, p = 0.0738, and for quadratic, p = 0.1066.

Fig. 6.14. The relationship between the mean numbers of cones / vine and the accumulative numbers of adult female mites / leaf on each plant.



For simple linear regression p = 0.2691, and quadratic p = 0.2647.

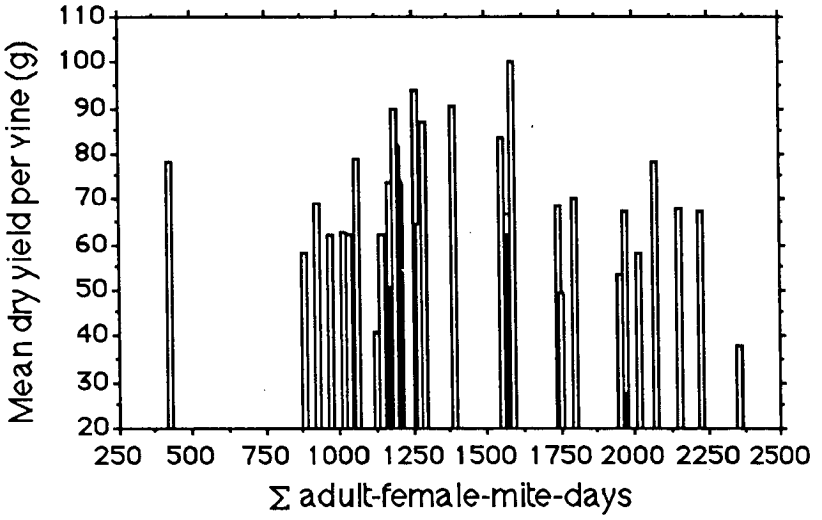
Fig. 6.15. The effect of accumulative numbers of adult female mites per leaf on mean cone size.



For simple linear regression, p = 0.1261, for quadratic p = 0.2970.

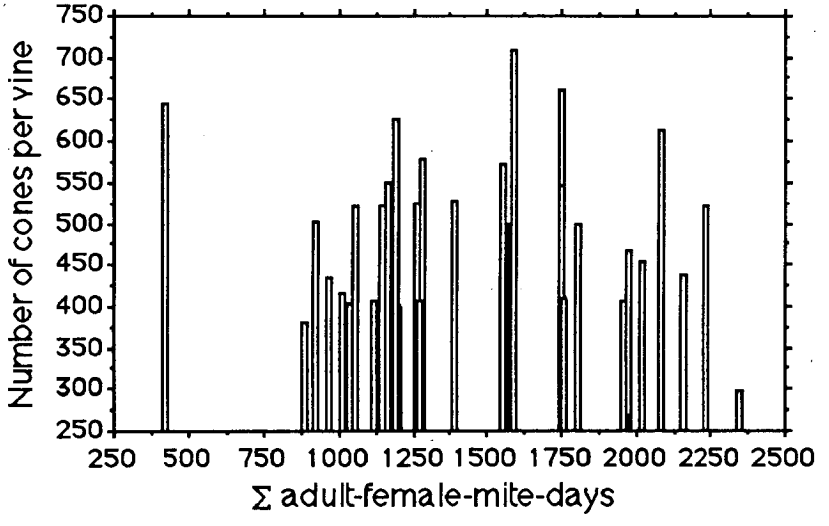
This obscurity remains, when the accumulative adult-female-mite-days per leaf for all single plants were related to the dry matter yield per vine (Fig. 6.16.), number of cones per vine (Fig. 6.17.) and cone size (Fig. 6.18.) from the corresponding plants. However, the fact that, some plants still gave moderate numbers of cones and reasonably high yields even though they had experienced a much greater mite feeding pressure than the commercial crop, would indicate that hop plants have a fairly high degree of tolerance to TSSM feeding.

Fig. 6.16. The relationship between the accumulative adult-female-mite-days per leaf and the dry yields per vine for each plant.



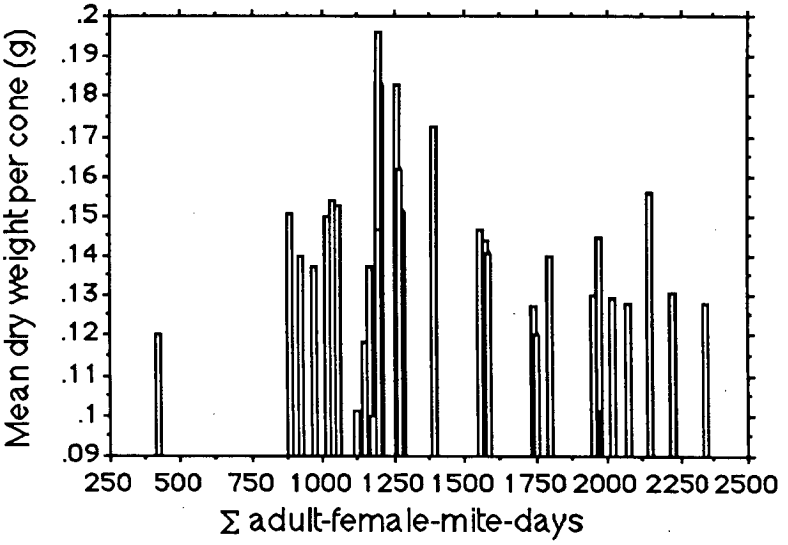
For simple linear regression, p = 0.1304, and for quadratic p = 0.1368.

Fig. 6.17. The relationship between the accumulative adult-female-mite-days per leaf and the mean numbers of cone per vine for each plant.



For simple linear regression p = 0.3423, and for quadratic p = 0.5560.

Fig. 6.18. The relationship between the accumulative adult-female-mite-days per leaf and the mean cone size for each plant.



For simple linear regression p = 0.2384, and quadratic p = 0.1940.

6.4. DISCUSSION

The results clearly show that appropriate control measures must be taken every year in order to minimize the damage caused by TSSM feeding, considering that losses up to 30 per cent in 1987-88 and 10 per cent in 1988-89 occurred in yield and the associated deterioration in quality as occurred on untreated hop plants. On the other hand, the result encouragingly demonstrated that losses in hop production could be effectively contained by either releasing natural predator, *Phytoseiulus persimilis*, or applying summer-oil/lime-sulphur three times or more per season.

6.4.1. Factors Influencing Hop Yield

Hop yields are ultimately determined by cone number and size ($r^2 = 0.967$ in 1987-88 and $r^2 = 0.987$ in 1988-89,). However, the numbers of cones played a very significant role, explaining nearly 70 per cent ($p <<< 0.05$) of the variation in yield in 1987-88 and 85 per cent ($p <<< 0.05$) in 1988-89, while cone size accounted for only 13 per cent ($p <<< 0.05$) in 1987-88 and was not significant ($p >>> 0.05$) in 1988-89. Meanwhile, the number of cones one plant could produce was significantly influenced by cone size. Plants having large cones produced fewer cones, with variation being explained by 5 per cent ($p < 0.05$) in 1987-88 and 25 per cent ($p <<< 0.05$) in 1988-89. Thus, although changes in either cone number or cone size influence the overall yield per plant, it is the change in cone numbers that determines the ultimate yield.

The results show that the mean cone size of the untreated crop, for either wet or dry cones, was the same as that of the commercial crop in both seasons (p's < 0.05), although numerically the mean cone size was smaller in the commercial crop in 1987-88 and slightly larger in 1988-89. However, the numbers of cones were significantly reduced in the untreated crop compared with the commercial crop. This loss of cones was approximately 36 per cent in 1987-88 which in turn caused approximately 30 per cent loss in dry hop yield. In 1988-89, though statistically they were equal, the numbers of cones in the commercial crop was 8 per cent more than that in the untreated crop and this resulted in approximately 10 per cent loss in dry yield. Thus, it can be concluded that the impact of TSSM feeding on hops is a great reduction in cone number rather than a reduction in cone size if all the other climatic and cultural factors are approximately the same. This conclusion supports the findings of Raworth (1986, a) that the fruit size of strawberry was not

affected by TSSM feeding, but is contrary to Sances *et al.* (1981) and Oatman *et al.* (1982) that the fruit size of strawberry was significantly reduced by TSSM feeding.

6.4.2. The Effect of Infestation at Different Times

It is unknown why TSSM feeding only caused reduction in cone number rather than cone size in hops. However, it is worthwhile to point out that from December 10, 1987 to around January 25 1988, all the treatments, with the exception of the commercial crop, were subjected to an increasing feeding pressure and that in 1988-89 it was also in this period that the untreated crop experienced greater mite feeding pressure than the commercial crop did. Considering this period is the pre-burr-forming time for hops (the normal commencing time for burrs formatting is around mid- to late January), this high feeding pressure would be suspected to be responsible for the following reduction in the number of burr-formation which led to fewer cones being produced by those plants experiencing such high feeding pressure.

This suggestion is strengthened when the mean numbers of cones per vine and the numbers of larvae plus nymphs (the main feeding group) per leaf on January 17, 1988 are compared:

Treatment	cone number	Treatment	L.&N./leaf
C-S	659	C-S	125.4
P-P	540	P-P	352.8
3-O	534	3-O	334.5
3-S	516	3-S	391.2
2-O	490	2-O	431.3
U-C	423	U-C	450
2-S	418	2-S	448.2.

Palpably, the lower the mite feeding pressure exerted on plant, the more cones the plant could produce (a very significant ($r^2 = 0.901$, $p << 0.05$) simple linear regression relationship). Therefore, it is in the period approximately five weeks before and up to burr formation that hop plants are most vulnerable to TSSM feeding that may cause significant reduction of cone number if it becomes intensive enough.

This also proves that the conventional spray programme, the first of which is normally applied approximately five to six weeks prior to the burr-formation time is strategically the best application time, for it enables hop plants to develop under a condition of very low mite feeding pressure so as to form normal, adequate number of cones.

The fact, that variable low to high mite feeding before December 10 scarcely impaired hop production in the commercial crop, would suggest that in this vegetative growth period, even intense mite feeding, does not economically affect the normal development of hop plants. In other words, hop plants exhibit high tolerance to mite infestation in the early vegetative developmental stages.

That no difference between the cone size of commercial crop and untreated control in both season, although the feeding pressure from mites was enormously different, would indicate that during cone ripening, three to four weeks after burr-formation began and lasting about another three to four weeks, hop plants displayed high degree of resistance to mite feeding, that is, mite feeding during or after this period would not necessarily cause the reduction in cone size. Moreover, the larger cones that occurred in 2-O, 3-O and 3-S would suggest a very strong compensatory effect by hop plants. In 1987-88, from February 14 1988 onward, the mite populations on 2-O, 3-O and 3-S treatment declined gradually in compliance with the climate.

Obviously this decline lessened the feeding pressure and provided the opportunity for hop plant quality to increase.

When hop plants suffered high mite feeding damage five weeks or so before burr formation, fewer cones were formed and those plants did actually compensate for the losses in cone number by increasing cone size so as to achieve maximum production. However, this may only occur when hop plants experienced low feeding pressure after burr formation is complete, as in the case in 2-O, 3-O, 3-S and P-P. If the feeding pressure was still very high after the completion of burr formation, even for plants that had fewer cones due to high mite infestation, there would be no such a compensation occurring, as the case of U-C. This compensation would not occur when hop plants had already formed the normal amount of cones as happened in the commercial crop.

An example with similar underlying is provided by Furr and Pfrimmer (1968) who found that only early- and mid-season (the time of fruit setting) infestations of TSSM caused significant reduction in cotton yield, and that late-season infested cotton did not reduce the yield, moreover it gave higher yields (6 per cent) than the control.

6.4.3. Relationship of Mite Density to Yield Production

While it is clear that the yield losses caused by unhindered mite feeding were 30 per cent in 1987-88 and 10 per cent in 1988-89, the relationship of mite density to yield loss is rather complex (Figs. 6.13.-18.).

The expression mite-days is considered a more appropriate measure of mite feeding pressure in yield-related studies (Wyman *et al.* 1979) and has been extensively used in studies of mite feeding on crops, especially on

strawberry (Oatman *et al.* 1981; Oatman *et al.* 1982; Raworth 1986; Sances *et al.* 1981; Wyman *et al.* 1979). Comparatively, the use of adult-female-mite-days in the present study would be less precise in expressing the actual mite feeding.

A knowledge of the effect of different levels of TSSM populations on crop yield is vital in establishing an economic threshold level for the mite infestation on crop. Wyman *et al.* (1979) found that although seasonal TSSM infestation levels ranged from 781 to 3631 mite-days /leaflet on strawberry plants, there were no yield differences between treatments at 25, 50, 75, and 100 mites (active stage)/leaflet level which were maintained throughout the season by applying cyhexatin at different frequencies. In fact, in untreated strawberry, even though the seasonal accumulation of mite-days /leaflet was 6261 in 1977 study, ten times as high as that of mite density treatment 0-5 mites (active stages)/leaflet, no differences between the total yield, nor fruit size occurred in the two groups of strawberry plants, with the yield numerically larger in the 0-5 treatment (34054 g) than in untreated plants (33806 g) and an equivalent fruit size (11.2 g).

This phenomenon, that only extremely high TSSM density can cause significant economic loss in strawberry yield and that a state of free or slight infestation of TSSM (0-5 mites/leaflet) did not result in maximum yield, occurred in three successive years studies by Wyman *et al.* (1979) as well as in the studies by Oatman *et al.* (1981 and 1982). Therefore, economic thresholds of 20-25 and 50 mites (active stages)/leaflet for winter- and summer-planted strawberry crop, respectively, are put forward for growers (Oatman *et al.* 1981, and 1982; Wyman *et al.* 1979). In fact, Oatman *et al.* (1981) showed that a density treatment level of 90-100 mites (active stages) /leaflet, about 3000 mite-days /leaflet totally, would provide

economically acceptable yield and fruit size for summer planted strawberry.

In the present study, hop plants exhibited high degree of tolerance and ability to compensate to TSSM feeding.

Those plants which received three applications of summer-oil. although produced the highest yield per vine, should be considered as an extreme example, for there were only three plants and one of them even had only one vine on each of two strings in the three strings the normal plants has.

Therefore, the production of commercial crop should be taken as the highest standard in comparing the production among treatments.

Considering the relations between cone number and cone size, the second commercial spray, applied on January 27 1988, would have a more important effect on reducing mite densities in order to prevent cones from being infested by mites (the market value of hops would be reduced if the cones were infested with mites) than on reducing mite densities in order to increase the hop yield. At this time, the majority of the mites are aggregated on the upper part of the crop. Thus the application of miticides with conventional tractor-drawn, air-blast sprayer, in the apical regions of hop plant, becomes rather difficult due to the heavily grown leaves and cones in the canopy (Sites and Cone 1985).

In 1987-88, the commercial crop experienced the lowest feeding pressure and produced the highest yield. Obviously, the two application of miticides proved to be adequate in controlling the mite on hops, even though the plants had 175 mites/leaf at early March. In fact, the production in all treatments would strongly indicate that hops can tolerate a fairly high infestation of TSSM without reducing their yield production.

Compared with strawberry, hops are much larger in plant itself and in the area of individual leaves. Oatman *et al.* (1981) proposed an economic threshold of 90-100 mites (active stages)/leaflet for TSSM on strawberry. As the hop leaf is much larger than the leaflet of strawberry, the economic threshold for TSSM on hops would be apparently higher than 100 mites (active stages)/leaf, which is actually lower than what the commercial crop had experienced in 1987-88 (Table 6.6.).

6.4.4. Limiting Factors

The results of this study was limited by a shortage of personnel to assist in more complete sampling of mite populations. Thus (1) not every adult female census was followed by counting of other mite stages, and (2) in some instances sampling was not undertaken on a regular basis, consequently mite population dynamics could not be traced thoroughly. Despite these limitations, as there is no information available yet on the effect of TSSM feeding on hop yield, the results from this study do provide some understanding and interpretation of the phenomenon of TSSM feeding on hops.

SYNTHESIS AND CONCLUSIONS

SYNTHESIS AND CONCLUSIONS

Four main topics are included in this study: (1) the biology and ecology of TSSM and its natural predators on hops; (2) the impact of TSSM on its host plants, hops; (3) the control of TSSM on hops, and (4) the assessment of TSSM densities on hops.

The Biology and Ecology of TSSM on Hops in Tasmania

For the first time, the biology and ecology of *Tetranychus urticae* Koch, the only pest on hops in Tasmania, have been investigated.

Adult female TSSM's, distributed contagiously, overwinter in the hollow cavities of hop twigs scattered around the base of hop plants. In late winter or early spring(from early August), overwintered females become active and move from their overwintering quarters. They first aggregate on the lower leaf surface of a green weed, California thistle (*Cirsium arvense* (L.) Scop.), which commences growing earlier than hops. No eggs are laid on thistles. When hop plants start shooting, mites transfer from thistles to hop leaves, mainly the lower surface. These mites lay their eggs as fast as possible, at 32 eggs/female for 16 days. The mortality rate of these eggs is approximately 15% under semi-natural conditions and this figure would be higher in hop fields when such factors as wind, rainfall, extremely low temperature and predation are taken into consideration. Early in the season, mite populations have a very high proportion of eggs. The teneral females conduct an upward movement with elongation of hop vines, but the height the mite reaches is scarcely over the 5th node from the plant tip. The distribution patterns of various stages of mites are different. Generally, populations at the highest level are young, having a

high percentage composition of eggs, while populations next to this level are rather mature, having a high percentage of larvae and nymphs cohort. A mature population has a stage composition of 1.5-2.0 percent adult female; 51-60 percent larvae and nymphs, and 38-47.5 percent of eggs. Soon after hop vines have reached their normal height, the majority of the mites aggregate on the upper part of hop plants, where the application of miticides becomes rather inefficient due to the dense canopy. In late season (early to mid-March), mites stop laying eggs therefore their populations have a high proportion of adult females, larvae and nymphs and a very low proportion of eggs. They move downward along the vines to seek overwintering refuges.

It is estimated that about 5-10 generations of TSSM may occur in each growing season in Tasmania.

The native predatory mite, *Amblyseius longispinosus* (Evans), overwinters in the litter around hop rootstocks. It actively consumes TSSM in the early stages of overwintering and immediately after overwintering. However, the numbers of this predator are not sufficient to suppress TSSM population development.

The introduced predatory mite, *Phytoseiulus persimilis* (A.-H.), does not overwinter in hop fields in Tasmania.

The Impact of TSSM on its Host Plant-Hops

To delineate the effect of TSSM infestation at various times, hop development in Tasmania may be divided into various stages: early vegetative growth; pre-burr-formation; burr forming, and cone ripening, according to the influence of mite feeding on hop yield production.

Normally, the period from early shooting of the hop plant until mid- or

late December (this varies with the climatic condition in the season) is the early vegetative growth stage. In this stage, plants can tolerate high intensity of mite feeding. Generally it is not necessary to apply miticides unless the mite infestation becomes extremely high.

The pre-burr formation stage, approximately the period between mid- or late December to early or mid-January, is very important with respect to hop production. In this stage, the plant is sensitive to mite infestation. Therefore, an elimination of mites from hop leaves during this period is essential for hop plants to form an adequate number of cones.

During the burr-forming and cone ripening stages, normally from mid- or late January to harvesting time, hop plants have a fairly high tolerance to mite feeding and yield would only be affected to some extent. However, one application of miticide may be necessary to keep cones from being infested by mites in order to maintain the market value of hop cones.

An economic threshold for TSSM on hops in Tasmania would be one higher than 100 mites (active stages) / leaf.

Further investigation of the interaction between hops and TSSM is essential for a complete IPM.

The Control of TSSM on Hops

The current control measures are effective in suppressing TSSM populations and protecting the market value of hops. However, as the ultimate object is to establish an IPM for TSSM on hops in Tasmania, some aspects of the alternative control measures should be taken into consideration.

Obviously, Summer-oil can effectively control TSSM on hops and therefore be recommended for further utilization. Although Lime-sulphur

is not so effective as Summer-oil, it can still be used alternatively with Summer-oil or other miticides. The most conspicuous advantage of using these two materials is that there is no residue on hop product.

In the light of biological control, there are two main hurdles to be overcome. The first is that more basic knowledge of the native predatory mite, *Amblyseius longispinosus*, is required. The predator alone cannot suppress TSSM populations effectively under natural conditions. It appears that the success of controlling TSSM on hops by this predatory mite will depend upon (1) the artificial augmentation of its population in late winter or early spring in order to have sufficient individuals to be released into hop fields, and (2) the availability of specific miticides which have no detrimental effect on the predator but can suppress TSSM effectively. The ultimate aim is the achievement of an equilibrium between TSSM and *A. longispinosus* in hop fields.

The second hurdle to overcome is that there would be more difficulty in using *Phytoseiulus persimilis* to control TSSM on hops in Tasmania. Since this mite cannot survive the cold winter in hop fields, it must be reintroduced every year. This will certainly reduce the practicability and increase the cost in hop production.

However, the major limiting factor for successful biological control using predators would appear to be the unreliability of the Tasmanian weather. Predator release in 1987-88 resulted in good establishment of predator in a good mite season. A similar release in 1988-89 failed shortly after cold and wet conditions reduced TSSM populations and the predator did not establish under these conditions.

The potential of cultural control is rather promising. Two aspects, which have direct influence on TSSM and are part of the conventional cultural activity, have been recognized in this study. Ploughing hop fields

at the appropriate time, late August or early September, can reduce the numbers of overwintered female TSSM and therefore retard the subsequent build up of TSSM populations. Proper irrigation of hop fields by sprinkler irrigation system also has a suppressing effect on TSSM densities. It is believed that more promising aspects could be recognized in further investigations.

The Assessment of TSSM Densities on Hops

When a mite-brushing machine is employed in mite sampling, the distribution of mites on the counting disc will be uniform if there are 8 or more mites (all stages) in each black section, i.e., a total of 1400 mites of all stages on the whole disc. If so, mite density can be estimated by counting 11 black sections in one counting track (one-sixteenth of the whole disc area) and then applying the established model to obtain the average numbers of mites on leaves.

In the field, mite densities can be estimated by counting either the numbers of adult female mites on the whole leaf, or numbers of all stages of mites on the middle part around the main vein with the naked eye, followed by a simple calculation with the models.

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APPENDICES

The following pagination conforms to the original draft and is subsequently plus five pages relative to the corrected body of the Thesis.

Appendix 3.1. The original record of numbers of mites found in B.C.T.'s.

												Total
Sampling Date: April 8, 1987												
T.urticae	Dead	18	32	2	104	325	6	8	3	0	5	503
	Alive	30	0	1	0	0	0	0	0	0	0	31
A. longispinosus	Dead	0	0	0	0	3	0	1	0	0	0	4
	Alive	13	2	2	3	3	1	3	3	3	3	36
April 29, 1987												
T.urticae	Dead	1	0	0	224	25	58	83	17	32	16	456
	Alive	0	0	1	2	1	2	0	1	0	0	7
A. longispinosus	Dead	1	0	0	6	0	6	0	0	0	0	13
	Alive	0	1	3	1	2	7	3	1	0	0	18
May 20, 1987												
T.urticae	Dead	0	8	160	22	125	4	9	87	18	139	572
	Alive	0	0	0	0	0	1	0	0	0	1	2
A. longispinosus	Dead	3	1	3	0	1	0	0	1	0	0	9
	Alive	0	1	0	0	0	0	0	2	0	4	7
June 10, 1987												
T.urticae	Dead	7	5	2	11	13	18	12	10	7	64	149
	Alive	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	Dead	0	0	0	0	0	0	0	0	0	0	0
	Alive	1	0	0	0	0	0	0	0	0	0	1
July 1, 1987												
T.urticae	Dead	5	7	8	8	103	204	3	21	11	99	469
	Alive	0	0	0	0	0	1	1	0	0	0	2
A. longispinosus	Dead	0	0	1	0	1	0	0	0	0	0	2
	Alive	o	2	1	0	0	0	0	0	1	5	9
July 19, 1987												
T.urticae	Dead	2	0	3	0	0	340	0	0	2	100	447
	Alive	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	Dead	0	0	0	0	0	0	0	0	0	0	0
	Alive	0	0	0	0	0	0	0	0	0	0	0
August 19, 1987												
T.urticae	Dead	2	0	0	2	2	0	9	8	5	0	28
	Alive	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	Dead	0	0	0	0	1	0	0	0	0	0	1
	Alive	0	0	0	0	0	0	0	0	0	0	0
September 8, 1987												
T.urticae	Dead	3	2	0	0	0	0	0	0	0	0	5
	Alive	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	Dead	0	0	0	0	0	0	0	0	0	0	0
	Alive	0	0	0	0	0	0	0	0	0	0	0
September 28, 1987												
T.urticae	Dead	0	0	0	0	0	6	0	0	239	0	245
	Alive	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	Dead	0	0	0	0	0	0	0	0	0	0	0
	Alive	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.2. The original record of numbers of mites from litter.

											Total
April 29, 1987											
T. urticae	1	1	7	0	0	0	13	1	0	0	23
A. longispinosus	0	0	2	2	2	4	3	1	0	2	16
May 20, 1987											
T. urticae	2	3	2	4	4	3	5	6	7	1	
	15	3	13	5	18	0	0	6	1	3	101
A. longispinosus	1	0	1	0	0	2	0	1	4	1	
	6	1	0	0	0	0	1	1	1	1	21
June 10, 1987											
T. urticae	0	0	2	1	0	8	0	0	0	0	
	12	0	0	4	0	0	0	0	0	2	29
A. longispinosus	0	0	0	0	0	1	0	0	0	1	
	0	1	1	0	1	2	0	0	0	1	8
July 19, 1987											
T. urticae	0	0	0	7	0	0	0	0	0	1	8
A. longispinosus	0	0	0	0	0	0	0	0	0	0	0
August 18, 1987											
T. urticae	0	0	0	0	0	0	0	0	0	0	
	0	1	4	0	1	2	0	1	0	2	11
A. longispinosus	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0
September 8, 1987											
T. urticae	0	0	0	0	0	0	0	0	0	0	
	0	1	0	0	0	0	1	0	0	0	2
A. longispinosus	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0
September 28, 1987											
T. urticae	0	0	0	0	0	0	0	0	0	0	0
A. longispinosus	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.3. Daily record of egg-laying for individual adult females.

Date	Days of oviposition	Designation of mites in culture (Dish A) 1	3	4	5	6	7	10	12	13	15	Total
9/25/1987	1	4	3	3	3	3	3	3.5	1	2	2	27.5
26-Sep	2	5	3	3.5	3	4.5	3.5	3.5	2.5	3.5	2.5	34.5
27-Sep	3	5	5	3.5	3	4.5	3.5	3.5	2.5	3.5	2.5	36.5
28-Sep	4	1.5	5	5.5	5	5	5.5	3.5	3.5	1	0.5	36
29-Sep	5	1.5	1.5	5.5	5	5	5.5	2.5	3.5	1	0.5	31.5
30-Sep	6	3	1.5	3	2	2	1	2.5	1.5	1	0.5	18
1-Oct	7	3	4	3	2	2	1	4.5	1.5	1	0.5	22.5
2-Oct	8	3	4	4.5	3	3	1	4.5	3.5	3.5	0	30
3-Oct	9	3	1.5	4.5	3	3	1	3.5	3.5	3.5	0	26.5
4-Oct	10	3	1.5	2	0.5	1		3.5	1	3	1.3	16.8
5-Oct	11	2	0.5	2	0.5	1	X	1	1	3	1.3	12.3
6-Oct	12	2	0.5			X		1		1	1.3	5.8
7-Oct	13	0.5						1		1	1.4	3.9
8-Oct	14	0.5						0.3		1	1.3	3.1
9-Oct	15	0.5						0.3		1	1.4	3.2
10-Oct	16	0.5						0.4			1.5	2.4
11-Oct	17	0.5						0.5	X	X	1.5	2.5
12-Oct	18	0.5						0.5			1.5	2.5
13-Oct	19		X	X				X			1.5	1.5
14-Oct	20				X							
15-Oct	21	X										
16-Oct	22											
17-Oct	23											
18-Oct	24											
19-Oct	25											
20-Oct	26										X	
Egg-laying period (Days)		18	12	11	11	11	9	18	11	15	19	135
Total eggs		39	31	40	30	34	25	40	25	30	23	317

X is the day the adult female died.

Date	Days of oviposition	Designation of mites in culture (Dish B) 2	4	5	6	7	8	10	11	14	Total
9/25/1987	1	2.5	2	2	1	0	0	0	1.5	3	12
26-Sep	2	2.5	3	4.5	2	2	3.5	8	2.5	3	31
27-Sep	3	3	3	4.5	2	2	3.5	8	3.5	3	32.5
28-Sep	4	3	4.5	3	3	1.5	6.5	4.5	3.5	2.5	32
29-Sep	5	3	4.5	3	3	1.5	6.5	4.5	1	2.5	29.5
30-Sep	6	0.5	2	3	1.5	1.5	2.5	1	1	1.5	14.5
1-Oct	7	0.5	2	3	1.5	1.5	2.5	1	0	1.5	13.5
2-Oct	8	1	3.5	3	2.5	2.5	3	2	0	2.5	20
3-Oct	9	1	3.5	3	2.5	2.5	3	2	2.5	2.5	22.5
4-Oct	10	0.5	1	2	1	2	1	2.5	2.5	2.5	15
5-Oct	11	0.5	1	2	1	2	1	2.5	2	2.5	14.5
6-Oct	12			0.5	0	1	1	0.5	2	0.5	5.5
7-Oct	13			0.5	0	1	1	0.5	1.5	0.5	5
8-Oct	14		X	0.6	0		1		1.5	1.7	4.8
9-Oct	15			0.7	0		1		2	1.6	5.3

10-Oct	16			0.7	0		1		2	1.7	5.4
11-Oct	17			1	1		0.5		2		4.5
12-Oct	18			1	1	X	0.5		2		4.5
13-Oct	19			X					2		2
14-Oct	20				X				1.5		1.5
15-Oct	21	X					X	X	1.5		1.5
16-Oct	22								2		2
17-Oct	23								2	X	2
18-Oct	24								X		
19-Oct	25										
20-Oct	26										
Egg-laying period (days)		11	11	18	18	12	17	12	23	16	138
Total eggs		18	30	38	23	21	39	37	42	33	281

X is the day the adult female died.

	Days of	Designation of mites in culture (Dish C)							
Date	oviposition	3	6	7	8	11	12	15	Total
9/25/1987	1	3	2	1	0	0	0	2	8
26-Sep	2	3	3.5	2.5	1.5	2	2.5	3	18
27-Sep	3	3	3.5	2.5	1.5	2	2.5	3	18
28-Sep	4	1.5	3.5	1	2.5	3	1	3.5	16
29-Sep	5	1.5	3.5	1	2.5	3	1	3.5	16
30-Sep	6	3	1.5	2	0.5	1	0.5	1	9.5
1-Oct	7	3	1.5	2	0.5	1	0.5	1	9.5
2-Oct	8	4	3	3.5	1	1	2	3.5	18
3-Oct	9	4	3	3.5	1	1	2	3.5	18
4-Oct	10	2.5	3	2	1	3	1	1.5	14
5-Oct	11	2.5	3	2	1	3	1	1.5	14
6-Oct	12	2	2	0.5		0.5	X		5
7-Oct	13	2	2	0.5		0.5			5
8-Oct	14	2	3		X			X	5
9-Oct	15	2	3	X					5
10-Oct	16		0.3						0.3
11-Oct	17	X	0.3						0.3
12-Oct	18		0.4						0.4
13-Oct	19		X						
14-Oct	20								
15-Oct	21					X			
16-Oct	22								
17-Oct	23								
18-Oct	24								
19-Oct	25								
20-Oct	26								
Egg-laying period (days)		15	18	13	10	12	10	11	89
Total eggs		39	42	24	13	21	14	27	180

X is the day the adult female died.

Date	Days of oviposition	Designation of mites in culture (Dish D) 5	6	8	9	10	13	Total
9/25/1987	1	1	3	4	0	5	0	13
26-Sep	2	3	4	1.5	2	4	4	18.5
27-Sep	3	3	4	1.5	2	4	4	18.5
28-Sep	4	0	3	3.5	2	6	2.5	17
29-Sep	5	0	3	3.5	2	6	2.5	17
30-Sep	6	1.5	2	2	2.5	2.5	1	11.5
1-Oct	7	1.5	2	2	2.5	2.5	1	11.5
2-Oct	8	1	4.5	3	3	3	3	17.5
3-Oct	9	1	4.5	3	3	3	3	17.5
4-Oct	10	2.5	2	2	3	3	0.5	13
5-Oct	11	2.5	2	2	3	3	0.5	13
6-Oct	12	1.5	2.5	2	2.5	3.5	1.5	13.5
7-Oct	13	1.5	2.5	2	2.5	3.5	1.5	13.5
8-Oct	14	1		2.5	1.5	4.5	0.5	10
9-Oct	15	1		2.5	1.5	4.5	0.5	10
10-Oct	16			1	0.5	1		2.5
11-Oct	17	X	X	1	0.5	1	X	2.5
12-Oct	18			1	1	3		5
13-Oct	19			1	1	3		5
14-Oct	20							
15-Oct	21			X	X			
16-Oct	22							
17-Oct	23							
18-Oct	24							
19-Oct	25							
20-Oct	26							
22-Oct	28					X		
Egg-laying period (days)		15	13	19	18	19	14	98
Total eggs		22	39	41	36	66	26	230

X is the day the adult female died.

Date	Days of oviposition	Designation of mites in culture (Dish E) 2	4	5	6	9	10	11	13	14	Total
9/25/1987	1	0	1	0	0	1	0	0	1	0	3
26-Sep	2	3	1	3	3.5	4	6	1	4	2.5	28
27-Sep	3	3	1	3	3.5	4	6	1	4	2.5	28
28-Sep	4	4	1.5	3	2.5	2	3	3	3.5	3	25.5
29-Sep	5	4	1.5	3	2.5	2	3	3	3.5	3	25.5
30-Sep	6	0.5	3	1	1	2	1.5	0	0	1	10
1-Oct	7	0.5	3	1	1	2	1.5	0	0	1	10
2-Oct	8	3.5	1.5	2.5	2	3	2	2	4	3	23.5
3-Oct	9	3.5	1.5	2.5	2	3	2	2	4	3	23.5
4-Oct	10	2	1	3	4.5	1	2	3.5	2	2	221
5-Oct	11	2	1	3	4.5	1	2	3.5	2	2	21
6-Oct	12	0.6	0.2	1.3	1.3	0.6	1.3	0.6	1	0.6	7.5
7-Oct	13	0.7	0.2	1.3	1.3	0.7	1.3	0.7	1	0.7	7.9
8-Oct	14	0.7	0.2	1.4	1.4	0.7	1.4	0.7	1	0.7	8.2
9-Oct	15	1.3	0.2	2	0		1	0.6	1.3	1.3	7.7
10-Oct	16	1.3	0.2	2	0		1	0.7	1.3	1.3	7.8

11-Oct	17	1.4		2	0	X	1	0.7	1.4	1.4	7.9
12-Oct	18	1		0	1		0.5	0	0.5	0.5	3.5
13-Oct	19	0.5		0	1		0.5	0	0.5	0.5	3
14-Oct	20	0.5		3.5	1.5		1	1	1		8.5
15-Oct	21	X	X	3.5	1.5		1	1	1		8
16-Oct	22			1					0.3		1.3
17-Oct	23			1				X	0.3		1.3
18-Oct	24			1			X		0.4	X	1.4
19-Oct	25			1					X		1
20-Oct	26										
21-Oct	27				X						
22-Oct	28			X							
Egg-laying period (days)		19	16	24	20	14	20	20	24	18	175
Total eggs		34	18	46	36	27	39	25	39	30	294

X is the day the adult female died.

Date	Days of oviposition	Designation of mites in culture (Dish F) 1	2	3	8	9	10	12	14	15	Total
9/25/1987	1	1	2	0	5	2	0	4	3	1	18
26-Sep	2	3.5	4	2	5	2.5	3	5.5	5.5	4.5	35.5
27-Sep	3	3.5	4	2	5	2.5	3	5.5	5.5	4.5	35.5
28-Sep	4	3.5	4	1	3	2.5	4	4	4	3	29
29-Sep	5	3.5	4	1	3	2.5	4	4	4	3	29
30-Sep	6	2	0.5	1.5	1.5	1	0.5	1.5	1	0.5	10
1-Oct	7	2	0.5	1.5	1.5	1	0.5	1.5	1	0.5	10
2-Oct	8	4	0.5	2	3.5	3	2.5	1.5	4.5	2.5	24
3-Oct	9	4	0.5	2	3.5	3	2.5	1.5	4.5	2.5	24
4-Oct	10	3.5	1	0	2.5	2		1.5	1	1	12.5
5-Oct	11	3.5	1	0	2.5	2		1.5	1	1	12.5
6-Oct	12	1.3		0.6	0.3	1		0.6	0.6	0	4.4
7-Oct	13	1.3		0.7	0.3	1		0.7	0.7	0	4.7
8-Oct	14	1.4		0.7	0.4	1		0.7	0.7	0	4.9
9-Oct	15	1.6		0.3	1.6	1		1.6	0.6	1	7.7
10-Oct	16	1.7		0.3	1.7	1		1.7	0.7	1	8.1
11-Oct	17	1.7		0.4	1.7	1		1.7	0.7	1	8.2
12-Oct	18	0.5				0.5					1
13-Oct	19	0.5			X	0.5					1
14-Oct	20	4				1.5	X				5.5
15-Oct	21	4		X		1.5		X	X	X	5.5
16-Oct	22	1									1
17-Oct	23	1									1
18-Oct	24	1	X			X					1
19-Oct	25										
20-Oct	26										
23-Oct	29	X									
Egg-laying period (days)		24	11	16	17	21	8	17	17	17	148
Total eggs		55	22	16	42	34	20	39	39	27	294

X is the day the adult female died.

Appendix 3.4. Daily record of larvae-hatching on leaf discs.

Date	Days	Designation in culture (dish A) 1	3	4	5	6	7	10	12	13	15	Total
OCT-1	1											
2	2											
3	3											
4	4	1			1				1	1		4
5	5	2		3	0	2	1		0	1		9
6	6	1		0	0	1	0		0	0		2
7	7	0	3	2	2	0	1		1	1		10
8	8	0	2	1	2	2	4	3	2	2		18
9	9	6	1	3	3	6	4	0	0	0		23
10	10	2	2	4	3	5	3	3	0	3		25
11	11	2	2	1	2	0	3	2	2	0		14
12	12	0	1	0	2	0	1	1	0	0		5
13	13	2	2	5	1	2	0	1	2	2		17
14	14	0	3	2	6	3	5	1	2	2		24
15	15	4	1	2	0	1	1	1	2	0		12
16	16	0	1	3	1	3	1	3	0	0		12
17	17	0	0	0	0	0	0	0	0	0		0
18	18	3	1	1	0	4	1	3	8	0		21
19	19	1	5	3	3	0		0	2	0		14
20	20	1	4	9	2	1		2	2	6		27
21	21	0	1	0	0	0		2	0	2		5
22	22	1	1	1	0	2		4	1	1	2	13
23	23	0	0		1	1		2		1	3	8
24	24	0	0					1			0	1
25	25	1	1								0	2
26	26										2	2
27	27										0	0
28	28										4	4
29	29										1	1
30	30										2	2
31	31											
NOV--1	32											
2	33											
3	34											
Hattching time (days)		22	19	18	20	19	14	17	19	20	9	177
Total larvae		27	31	40	29	33	25	29	25	22	14	275

Date	Days	Designation in culture (dish B) 2	4	5	6	7	8	10	11	14	Total
OCT.1	1								2		2
2	2								0		0
3	3								0		0
4	4			1			1	4	0		6
5	5	1	1	1			2	0	1	1	7
6	6	0	0	1			0	0	2	0	3
7	7	2	0	0	1	2	0	0	0	2	7
8	8	2	1	2	1	0	2	4	2	1	15

9	9	3	2	2	0	1	0	2	0	0	10
10	10	2	2	3	2	1	4	4	1	3	22
11	11	0	1	2	3	1	1	3	2	0	13
12	12	1	1	1	1	1	1	0	0	0	6
13	13	2	2	3	1	0	2	1	0	0	11
14	14	1	1	1	2	1	0	1	0	0	7
15	15	1	3	0	1	2	4	4	2	2	19
16	16	0	1	2	0	2	0	0	0	1	6
17	17	0	0	0	0	0	0	0	0	0	0
18	18	0	3	5	4	2	1	5	1	4	25
19	19	2	1	1	1	0	2	1	3	1	12
20	20		3	3	0	1	1	1	3	1	13
21	21		0	0	1	2		2	1	2	8
22	22		2	3	1	0		0	4	0	10
23	23		1	1	0	1		1	2	0	6
24	24		0	1	1	0			0	0	2
25	25		1			1			5	0	7
26	26								0	1	1
27	27								0	2	2
28	28								5		5
29	29								2		2
30	30								1		1
31	31										
NOV.1	32										
2	33										
3	34										
Hatching time (days)		15	21	21	18	19	17	20	31	23	185
Total larvae		17	26	33	20	18	21	33	39	21	228

Date	Days	Designation in culture (dish C) 3	6	7	8	11	12	15	Total
OCT.1	1								0
2	2								0
3	3								0
4	4								0
5	5								0
6	6								0
7	7	1	1	2					4
8	8	1	1	1	1			2	6
9	9	0	2	0	0			0	2
10	10	6	4	2	3	1		3	19
11	11	3	1	1	0	4	1	1	11
12	12	2	0	0	0	0	0	0	2
13	13	2	2	1	0	0	0	2	7
14	14	0	1	0	0	1	0	1	3
15	15	0	4	3	5	1	0	4	17
16	16	3	0	0	0	0	0	1	4
17	17	5	1	0	0	0	1	1	8
18	18	4	7	4	1	1	2	4	23
19	19	2	2	0	1	3	0	1	9
20	20	2	1	3		1	2	2	11
21	21	2	0	1		1			4

22	22	2	1	3		0		6
23	23	1	1			1		3
24	24	2				3		5
25	25	1						1
26	26	1						1
27	27							0
28	28							0
29	29							0
30	30							0
31	31							0
NOV.1	32							0
2	33							0
3	34							0
Hatching period (days)		20	17	16	12	15	10	13	103
Total larvae		38	31	21	11	17	6	22	146

Date	Days	Designation in culture (dish D) 5	6	8	9	10	13	Total
OCT.1	1							0
2	2							0
3	3							0
4	4							0
5	5	1	2			1		4
6	6	0	0			2		2
7	7	3	2			2	2	9
8	8	2	0	1		3	2	8
9	9	0	3	0		2	2	7
10	10	1	3	3		5	2	14
11	11	0	2	0	1	2	1	6
12	12	0	0	0	2	0	0	2
13	13	0	0	0	1	4	1	6
14	14	0	1	0	2	1	1	5
15	15	0	6	5	2	5	3	21
16	16	1	1	0	3	1	2	8
17	17	2	3	0	2	1	1	9
18	18	0	3	5	3	4	6	21
19	19	2	0	1	1	2	2	8
20	20	4	3	0	1	2	0	10
21	21	0	1	0	1	0	0	2
22	22	2	1	0	1	0	0	4
23	23	1	0	2	5	8	2	18
24	24	3	0	0	0	3		6
25	25		1	0	3	0		4
26	26			4		3		7
27	27							0
28	28							0
29	29							0
30	30							0
31	31							0
NOV.1	32							0
2	33							0

3	34									0
Hatching period (days)		20	21	17	15	22	17			112
Total larvae		22	32	23	28	51	25			181

	Days	Designation in culture (dish E)									
Date		2	4	5	6	9	10	11	13	14	Total
OCT.1	1										0
2	2										0
3	3	1									1
4	4	0									0
5	5	0				1	1				2
6	6	3				2	1				6
7	7	1	1		1	1	2		1		7
8	8	4	0	1	1	2	2		1		11
9	9	1	3	2	1	1	2		0	1	11
10	10	0	0	1	2	2	3	4	0	1	13
11	11	2	0	0	0	0	3	0	3	1	9
12	12	0	0	3	0	1	0	1	0	0	5
13	13	2	0	0	0	1	1	2	0	2	8
14	14	0	1	3	2	3	1	0	0	1	11
15	15	0	0	0	3	0	4	2	0	4	13
16	16	4	0	0	0	2	0	1	0	0	7
17	17	1	0	0	0	0	0	1	0	1	3
18	18	4	4	4	2	0	0	0	3	0	17
19	19	1	0	3	4	5	6	4	0	3	26
20	20	0	1	0	3	1	3	4	6	2	20
21	21	3	0	1	1		1	0	0	0	6
22	22	0	3	7	1		0	1	3	0	15
23	23	1	2	5	5		2	0	1	1	17
24	24	1	1	1	2		1	5	3	4	18
25	25	2	0	4	1		1	0	3	0	11
26	26	1	1	1	2		1	1	2	2	11
27	27	1		0	2			0	0		3
28	28			5	0			2	1		8
29	29				0			0	0		0
30	30				2			0	1		3
31	31							0	2		2
NOV.1	32							4			4
2	33							2			2
3	34							1			1
Hatching period (days)		23	20	21	24	16	22	25	25	18	194
Total larvae		33	17	42	35	24	35	25	35	25	271

Date	Days	Designation in culture (dish F) 1	2	3	8	9	10	12	14	15	Total
OCT.1	1										0
2	2										0
3	3										0
4	4							1	1		2
5	5				2	1		2	1	1	7
6	6				1	0		0	1	1	3
7	7	3	3		2	1		6	3	1	19
8	8	0	2	1	2	1		2	3	5	16
9	9	2	1	1	3	2		3	2	0	14
10	10	3	3	0	1	2	4	2	2	2	19
11	11	2	3	0	0	2	2	1	3	1	14
12	12	0	0	0	1	0	0	0	0	0	1
13	13	1	2	0	2	1	1	3	0	1	11
14	14	4	2	2	4	1	5	3	1	3	25
15	15	0	3	4	0	3	2	4	2	1	19
16	16	3	0	1	0	1	1	1	6	0	13
17	17	0	1	0	0	0	0	0	0	0	1
18	18	1	1	1	0	1	0	3	5	0	12
19	19	5	0	1	4	3	3	0	3	0	19
20	20	5	1	1	4	4	0	0	2	2	19
21	21	2	0	0	0	0	1	2	4	2	11
22	22	2	0	1	2	0		2	0	0	7
23	23	4	0	0	1	2		1	0	0	8
24	24	3	1	1	1	2		2	1	1	12
25	25	2	0	0	2	2		2		0	8
26	26	2	1	1		1				1	6
27	27	1				2					3
28	28	3				1					4
29	29	2									2
30	30	3									3
31	31	1									1
NOV.1	32										0
2	33										0
3	34										0
Hatching period (days)		25	20	19	21	24	12	22	21	22	186
Total larvae		54	22	15	36	33	19	38	38	24	279

Appendix 4.1. The analyses of variance, coefficient of variantion, and coefficient of dispersion of various stages of TSSM on counting disc.

A. for eggs.

a. For Height: 0-90 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	3	1	0	0	4	4	1	1.41	1.19	119	1.41
2	4	1	2	2	4	9	2.25	1.26	1.12	50	0.56
3	9	6	9	9	4	33	8.25	1.5	1.23	15	0.18
4	9	8	9	7	4	33	8.25	0.96	0.98	12	0.12
5	1	6	7	9	4	23	5.75	3.4	1.85	32	0.59
6	1	3	10	7	4	21	5.25	4.03	2.01	38	0.77
7	3	5	5	4	4	17	4.25	0.96	0.98	23	0.23
8	1	3	1	2	4	7	1.75	0.96	0.98	56	0.55
9	3	6	2	5	4	16	4	1.83	1.35	34	0.46
10	3	2	0	3	4	8	2	1.41	1.19	60	0.71
11	0	2	1	2	4	5	1.25	0.96	0.98	78	0.77

b. For Height: 90-180 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	4	2	4	6	1.5	1.92	1.38	92	1.28
2	3	2	4	4	4	13	3.25	0.96	0.98	30	0.30
3	6	11	9	11	4	37	9.25	2.36	1.54	17	0.26
4	5	10	6	11	4	32	8	2.94	1.72	22	0.37
5	10	7	10	7	4	34	8.5	1.73	1.32	16	0.20
6	8	2	4	10	4	24	6	3.65	1.91	32	0.61
7	9	4	11	9	4	33	8.25	2.99	1.73	21	0.36
8	3	7	5	4	4	19	4.75	1.71	1.31	28	0.36
9	7	9	3	3	4	22	5.5	3	1.73	32	0.55
10	4	0	5	3	4	12	3	2.16	1.47	49	0.72
11	4	3	1	2	4	10	2.5	1.29	1.14	46	0.52

c. For Height 180-270 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	9	4	4	13	3.25	4.27	2.07	64	1.32
2	12	22	16	11	4	61	15.25	4.99	2.23	15	0.33
3	21	24	7	13	4	65	16.25	7.72	2.78	17	0.48
4	18	15	14	10	4	57	14.25	3.30	1.82	13	0.23
5	10	13	6	17	4	46	11.5	4.66	2.16	19	0.41
6	14	7	16	10	4	47	11.75	4.03	2.01	17	0.34

7	11	10	7	11	4	39	9.75	1.89	1.38	14	0.19
8	9	10	8	9	4	36	9	0.82	0.90	10	0.09
9	6	7	6	8	4	27	6.75	0.96	0.98	15	0.14
10	6	3	4	9	4	22	5.5	2.65	1.63	30	0.48
11	4	6	0	2	4	12	3	2.58	1.61	54	0.86

d. For Height: 270-360 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	2	20	20	2	4	44	11	10.39	3.22	29	0.95
2	39	57	49	25	4	170	42.5	13.8	3.71	9	0.33
3	70	69	42	43	4	224	56	15.6	3.95	7	0.28
4	50	66	46	39	4	201	50.25	11.44	3.28	7	0.23
5	37	36	42	38	4	153	38.25	2.63	1.62	4	0.07
6	39	29	23	37	4	128	32	7.39	2.72	9	0.23
7	33	32	36	28	4	129	32.25	3.30	1.82	6	0.10
8	23	25	26	22	4	96	24	1.83	1.35	6	0.08
9	17	23	25	37	4	102	25.5	8.39	2.90	11	0.33
10	33	23	21	8	4	85	21.25	10.28	3.21	15	0.48
11	14	22	7	12	4	55	13.75	6.24	2.50	18	0.45

e. For Height: 360-550 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	4	8	13	0	4	25	6.25	5.56	2.36	38	0.89
2	33	44	31	40	4	148	37	6.06	2.46	7	0.16
3	51	62	61	54	4	228	57	5.35	2.31	4	0.09
4	62	90	80	49	4	281	70.25	18.30	4.28	6	0.26
5	34	54	62	45	4	195	48.75	12.04	3.47	7	0.25
6	40	43	43	42	4	168	42	1.41	1.19	3	0.03
7	39	33	34	41	4	147	36.75	3.86	1.97	5	0.11
8	41	35	28	39	4	143	35.75	5.74	2.40	7	0.16
9	31	16	37	25	4	109	27.25	8.96	2.99	11	0.33
10	14	22	13	22	4	71	17.75	4.92	2.22	13	0.28
11	20	8	9	12	4	49	12.25	5.44	2.33	19	0.44

f. for different heights

	0-90	90-180	180-270	270-360	360-550
n	44	44	44	44	44
Σx	177	242	425	1387	1564
Meanx	4.02	5.5	9.66	31.52	35.55
s^2	3.05	3.35	5.65	16.07	19.86
s	1.75	1.83	2.38	4.01	4.46
C. V.%	43	33	25	13	13
C. D.	0.76	0.61	0.59	0.51	0.56

Appendix 4.1. B. for larvae plus nymphs.

a. For Height 0-90 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	3	4	2	2	4	11	2.75	0.96	0.98	36	0.35
2	6	3	7	6	4	22	5.5	1.73	1.32	24	0.32
3	8	7	6	12	4	33	8.25	2.63	1.62	20	0.32
4	7	4	8	11	4	30	7.5	2.89	1.70	23	0.39
5	7	8	5	10	4	30	7.5	2.08	1.44	19	0.28
6	7	6	8	3	4	24	6	2.16	1.47	25	0.36
7	2	7	4	3	4	16	4	2.16	1.47	37	0.54
8	4	6	6	4	4	20	5	1.16	1.08	22	.23
9	3	3	5	2	4	13	3.25	1.26	1.12	35	0.39
10	2	4	2	4	4	12	3	1.16	1.08	36	0.39
11	0	1	1	1	4	3	0.75	0.5	0.71	94	0.17

b. For Height: 90-180 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	1	2	4	4	4	11	2.75	1.5	1.23	45	0.55
2	3	6	8	6	4	23	5.75	2.06	1.44	25	0.36
3	18	12	17	18	4	65	16.25	2.87	1.70	10	0.18
4	15	15	11	17	4	58	14.5	2.52	1.59	11	0.17
5	14	9	8	13	4	44	11	2.94	1.72	16	0.27
6	18	13	15	11	4	57	14.25	2.99	1.73	12	0.21
7	14	4	7	10	4	35	8.75	4.27	2.07	24	0.48
8	11	6	10	5	4	32	8	2.94	1.72	22	0.37
9	5	8	4	8	4	25	6.25	2.06	1.44	23	0.33
10	7	6	11	3	4	27	6.75	3.30	1.82	27	0.49
11	5	4	1	4	4	14	3.5	1.73	1.32	38	0.50

c. For Height 180-270 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	10	3	9	17	4	39	9.75	5.74	2.40	25	0.59
2	28	35	31	39	4	133	33.25	4.79	2.19	7	0.14
3	41	53	35	29	4	158	39.5	10.25	3.2	8	0.26
4	51	47	38	45	4	181	45.25	5.44	2.33	5	0.12
5	41	45	26	34	4	146	36.5	8.35	2.89	8	0.23
6	27	29	38	26	4	120	30	5.48	2.34	8	0.18
7	27	21	20	21	4	89	22.25	3.20	1.79	8	0.14
8	21	19	17	23	4	80	20	2.58	1.61	8	0.13
9	14	20	19	16	4	69	17.25	2.75	1.66	10	0.16
10	11	11	13	11	4	46	11.5	1	1	9	0.09
11	5	4	8	9	4	26	6.5	2.38	1.54	24	0.37

d. For Height: 270-360 cm.cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	7	13	27	5	4	52	13	9.93	3.15	24	0.76
2	31	57	40	25	4	153	38.25	13.94	3.73	10	0.36
3	81	79	46	50	4	256	64	18.57	4.31	7	0.29
4	66	53	67	53	4	239	59.75	7.81	2.79	5	0.13
5	57	50	57	55	4	219	54.75	3.30	1.82	3	0.06
6	48	43	40	45	4	176	44	3.37	1.83	4	0.08
7	55	27	40	37	4	159	39.75	11.59	3.40	9	0.29
8	29	21	23	32	4	105	26.25	5.12	2.26	9	0.20
9	19	25	30	22	4	96	24	4.69	2.17	9	0.20
10	53	15	29	19	4	116	29	17.05	4.13	14	0.59
11	13	15	12	9	4	49	12.25	2.5	1.58	13	0.20

e. For Height: 360-550 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	2	7	4	2	4	15	3.75	2.36	1.54	41	0.63
2	16	27	10	11	4	64	16	7.79	2.79	17	0.49
3	35	20	25	26	4	106	26.5	6.25	2.5	9	0.24
4	31	33	36	31	4	131	32.75	2.36	1.54	5	0.07
5	28	18	28	21	4	95	23.75	5.06	2.25	10	0.21
6	26	25	27	29	4	107	26.75	1.71	1.31	5	0.06
7	23	18	13	18	4	72	18	4.08	2.02	11	0.23
8	9	17	27	6	4	59	14.75	9.39	3.07	21	0.64
9	11	9	9	10	4	39	9.75	0.96	0.98	10	0.10
10	8	11	14	15	4	48	12	3.16	1.78	15	0.26
11	8	4	5	5	4	22	5.5	1.73	1.32	24	0.32

f. for different heights

	0-90	90-180	180-270	270-360	360-550
n	44	44	44	44	44
Σx	214	391	1087	1620	758
Meanx	4.86	8.89	24.71	36.82	17.23
s^2	2.78	5.02	13.42	19.43	9.95
s	1.67	2.24	3.66	4.41	3.16
C.V.%	34	25	15	12	18
C. D.	0.57	0.57	0.54	0.53	0.58

Appendix 4.1.C. for adult female mites.

a. For Height 0-90 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	0	0	4						
2	0	0	0	0	4						
3	0	1	0	0	4	1	0.25	0.5	0.71	283	2
4	0	0	0	1	4	1	0.25	0.5	0.71	283	2
5	0	0	0	0	4						
6	0	0	0	0	4						
7	0	0	0	0	4						
8	0	0	0	0	4						
9	0	0	0	0	4						
10	0	0	0	0	4						
11	1	0	0	0	4	1	0.25	0.5	0.71	283	2

b. For Height 90-180 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	1	0	0	0	4	1	0.25	0.5	0.71	283	2
2	0	0	0	0	4						
3	0	0	0	0	4						
4	0	0	0	0	4						
5	0	0	1	1	4	2	0.5	0.58	0.76	152	1.16
6	0	0	0	0	4						
7	0	0	0	0	4						
8	0	0	0	0	4						
9	0	1	0	0	4	1	0.25	0.5	0.71	283	2
10	0	0	0	0	4						
11	0	0	0	0	4						

c. For Height 180-270 cm.

Sections	Counting Directions								Within annulus		
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	1	0	4	1	0.25	0.5	0.71	283	2
2	0	0	0	0	4						
3	0	0	0	0	4						
4	0	0	0	0	4						
5	1	0	1	1	4	3	0.75	0.5	0.71	94	0.67
6	0	0	0	1	4	1	0.25	0.5	0.71	283	2
7	0	0	1	0	4	1	0.25	0.5	0.71	283	2
8	0	0	0	0	4						
9	0	0	0	0	4						
10	1	1	0	0	4	2	0.5	0.58	0.76	152	1.16
11	0	0	0	0	4						

d. For Height 270-360cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	0	0	4						
2	1	0	0	0	4	1	0.25	0.5	0.71	283	2
3	1	2	0	0	4	3	0.75	0.96	0.98	131	1.28
4	1	2	1	1	4	5	1.25	0.5	0.71	57	0.4
5	0	0	0	1	4	1	0.25	0.5	0.71	283	2
6	2	0	0	2	4	4	1	1.16	1.08	108	1.16
7	1	0	0	1	4	2	0.5	0.58	0.76	152	1.16
8	1	1	1	1	4	4	1	0			
9	0	1	1	0	4	2	0.5	0.58	0.76	152	1.16
10	1	1	2	0	4	4	1	0.82	0.90	90	0.82
11	0	0	1	0	4	1	0.25	0.5	0.71	283	2

e. For Height 360-550 cm.

Sections	Counting Directions							within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	0	0	1	1	4	2	0.5	0.58	0.76	152	1.16
2	0	0	2	0	4	2	0.5	1	1	200	2
3	2	3	0	0	4	5	1.25	1.5	1.23	98	1.2
4	1	3	1	2	4	7	1.75	0.96	0.98	56	0.55
5	2	1	2	0	4	5	1.25	0.96	0.98	78	0.77
6	1	1	0	1	4	3	0.75	0.5	0.71	94	0.67
7	3	0	2	1	4	6	1.5	1.29	1.14	76	0.86
8	0	3	2	1	4	6	1.5	1.29	1.14	76	0.86
9	1	0	0	0	4	1	0.25	0.5	0.71	283	2
10	1	1	0	1	4	3	0.75	0.5	0.71	94	0.67
11	1	1	1	0	4	3	0.75	0.5	0.71	94	0.67

f. for different heights

	0-90	90-180	180-270	270-360	360-550
n	44	44	44	44	44
Σx	3	4	8	27	43
Meanx	0.07	0.09	0.18	0.61	0.98
s^2	0.26	0.29	0.39	0.69	0.95
s	0.51	0.54	0.63	0.83	0.98
C. V. %	741	593	344	135	100
C. D.	3.74	3.20	2.15	1.12	0.97

Appendix 4.1.D. for all stages of mites.

a. Height 0-90 cm.

Sections	Counting Directions							Within annulus			
	8-2	2-4	4-6	6-8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	6	5	2	2	4	15	3.75	2.06	1.44	38	0.55
2	10	4	9	8	4	31	7.75	2.63	1.62	21	0.34
3	17	14	15	21	4	67	16.75	3.10	1.76	11	0.19
4	16	12	17	19	4	64	16.00	2.94	1.72	11	0.18
5	8	14	12	19	4	53	13.25	4.57	2.14	16	0.35
6	8	9	18	10	4	45	11.25	4.57	2.14	19	0.41
7	5	12	9	7	4	33	8.25	2.99	1.73	21	0.36
8	5	9	7	6	4	27	6.75	1.71	1.31	19	0.25
9	6	9	7	7	4	29	7.25	1.26	1.12	16	0.17
10	5	6	2	7	4	20	5.00	2.16	1.47	29	0.43
11	1	3	2	3	4	9	2.25	0.96	0.98	44	0.43

b. Height 90-180 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	2	2	8	6	4	18	4.50	3.00	1.73	38	0.67
2	6	8	12	10	4	36	9.00	2.58	1.61	18	0.29
3	24	13	26	30	4	93	23.25	7.27	2.70	12	0.31
4	20	25	17	28	4	90	22.50	4.93	2.22	10	0.22
5	24	16	19	21	4	80	20.00	3.37	1.83	9	0.17
6	26	15	19	21	4	81	20.25	4.57	2.14	11	0.23
7	23	8	18	19	4	68	17.00	6.38	2.53	15	0.38
8	14	13	15	9	4	51	12.75	2.63	1.62	13	0.21
9	12	18	7	11	4	48	12.00	4.55	2.13	18	0.38
10	11	6	16	6	4	39	9.75	4.79	2.19	23	0.49
11	9	7	2	6	4	24	6.00	2.94	1.72	29	0.49

c. For Height 180-270 cm.

Sections	Counting Directions							Within annulus			
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	10	3	19	21	4	53	13.25	8.34	2.89	22	0.63
2	40	57	47	50	4	194	48.50	7.05	2.66	6	0.15
3	62	77	42	42	4	223	55.75	17.02	4.13	7	0.31
4	69	62	53	55	4	239	59.75	7.27	2.7	5	0.12
5	52	58	32	54	4	196	49.00	4.61	3.41	7	0.09
6	41	36	54	37	4	168	42.00	8.29	2.88	7	0.2
7	38	31	28	32	4	129	32.25	4.19	2.05	6	0.13
8	30	29	25	32	4	119	29.75	1.71	1.31	4	0.06
9	20	27	25	24	4	96	24.00	2.94	1.72	7	0.12
10	17	15	17	20	4	69	17.25	2.06	1.44	8	0.12
11	9	10	8	11	4	38	9.50	1.29	1.14	12	0.14

d. For Height 270-360 cm.

Sections	Counting Directions				Within annulus						
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	9	33	47	7	4	96	24.00	19.36	4.4	18	0.81
2	71	114	89	50	4	324	81.00	27.17	5.21	6	0.34
3	152	150	88	93	4	483	120.75	35.00	5.92	5	0.29
4	117	121	114	94	4	446	111.50	12.01	3.47	3	0.11
5	96	86	99	94	4	375	93.75	5.56	2.34	3	0.06
6	88	72	63	84	4	307	76.75	11.41	3.38	4	0.15
7	88	59	76	66	4	289	72.25	12.61	3.55	5	0.18
8	53	47	50	55	4	205	51.25	3.50	1.87	4	0.07
9	36	49	56	59	4	200	50.00	10.23	3.2	6	0.21
10	87	38	52	27	4	204	51.00	26.09	5.11	10	0.51
11	27	38	20	21	4	106	26.50	8.27	2.88	11	0.31

e. For Height 360-550 cm.

Sections	Counting Directions				Within annulus						
	8--2	2--4	4--6	6--8	n	Σx	M. x	s^2	s	C.V. %	C. D.
1	6	15	18	3	4	42	10.50	7.14	2.67	25	0.68
2	49	71	43	51	4	214	53.50	12.15	3.49	7	0.23
3	88	85	86	80	4	339	84.75	3.40	1.85	2	0.04
4	94	126	117	82	4	419	104.75	20.29	4.50	4	0.19
5	64	73	92	66	4	295	73.75	12.76	3.57	5	0.17
6	67	68	70	72	4	277	69.25	2.22	1.49	2	0.03
7	65	51	49	60	4	225	56.25	7.54	2.75	5	0.13
8	50	55	57	46	4	208	52.00	4.97	2.23	4	0.10
9	33	26	46	35	4	140	35.00	8.29	2.88	8	0.24
10	23	34	27	38	4	122	30.50	6.76	2.60	9	0.22
11	29	12	15	17	4	73	18.25	7.46	2.73	15	0.41

f. For different heights

	0-90	90-180	180-270	270-360	360-550
n	44	44	44	44	44
Σx	393	628	1521	3035	2354
Mean x	8.93	14.27	34.57	68.98	53.50
s^2	5.28	7.55	18.30	34.63	28.96
s	2.30	2.75	4.28	5.89	5.38
C. V. (%)	26	19	12	9	10
C. D.	0.59	0.53	0.53	0.50	0.54

Appendix 4.2. Original record of numbers of adult female mites and that of all stages of mites on whole leaves and on various parts of leaves; and the measurements of leaf area, the length and width, area of the fictious triangle.

A. The record of number of mites on leaf and in various parts and their percentages.

Sum All stages	Sum LM+RM	Sum LM+RM + MD	% LM+RM	% LM+RM + MD	Sum All stages	Sum LM+RM + MD	Sum LM+RM	% LM+RM + MD	% LM+RM
12	12	12	100	100	377	164	164	44	44
14	10	11	79	71	420	246	246	59	59
53	21	21	40	40	339	164	209	62	48
6	0	6	100	0	264	90	199	75	34
117	27	69	59	23	174	69	93	54	40
184	39	120	65	21	6	0	0	0	0
624	228	351	56	37	36	36	36	100	100
707	122	254	36	17	316	211	217	69	67
185	60	91	49	32	409	164	176	43	40
212	62	130	61	29	41	25	36	88	61
19	0	1	5	0	956	251	580	61	26
217	63	64	67	29	12	8	11	92	67
268	92	145	54	34	70	47	47	67	67
759	366	573	62	48	37	11	14	38	30
128	21	22	17	16	17	16	16	94	94
179	71	90	50	40	29	8	10	35	28
468	240	256	55	51	258	64	102	40	25
434	153	196	45	35	101	34	74	73	34
148	54	61	41	37	70	13	48	69	19
195	85	117	60	44	22	17	18	82	77
268	72	112	42	27	90	47	55	61	52
5	1	1	20	20	7	5	6	86	71
252	122	163	65	48	327	125	172	53	38
190	178	178	94	94	329	138	197	60	42
342	171	171	50	50	93	37	40	43	40
235	235	235	100	100	23	6	8	35	26
1	1	1	100	100	489	185	150	51	38
107	95	97	91	89	6	0	6	100	0
317	187	191	60	59	8	1	1	25	13
134	105	133	99	78	91	26	46	54	29
103	92	92	89	89	302	41	176	58	14
144	119	120	83	83	122	56	56	46	46
153	93	116	76	61	151	78	92	61	52
18	0	0	0	0	519	108	171	33	21
16	16	16	100	100	173	61	101	58	35
4	0	0	0	0	131	13	45	34	10
138	79	79	57	57	300	66	99	33	22
104	61	97	93	59	270	87	147	54	32

200	151	167	84	76	26	0	12	46	0
203	84	84	41	41	116	49	49	42	42
50	31	31	62	62	38	10	16	42	26
180	148	148	82	82	7	2	2	29	29
95	59	60	63	62	160	65	142	89	41
215	32	44	21	15	717	250	257	36	35
124	91	91	73	73	151	56	66	44	37
254	190	201	79	75	204	50	86	42	25
266	142	142	53	53	16	15	15	94	94
192	131	131	68	68	342	139	205	57	41
238	207	207	87	87	182	87	104	46	48
210	116	116	55	55	198	77	93	47	39
259	149	149	58	58	4	2	2	50	50
312	164	170	55	53	338	129	173	51	38
842	370	482	57	44	231	38	90	39	17
43	4	20	47	9	136	38	54	40	28
316	183	214	68	58	154	66	82	53	43
243	106	122	50	44	384	67	136	35	17
					48	14	25	52	29

B. The original record of number of adult female mites and all stages of mites on single leaves.

Adult females on leaf	All mite stages on leaf	Adult females in triangle	Adult females on leaf	All mits stages on leaf	Adult females in triangle
2	6	0	40	707	11
2	8	1	7	184	2
2	91	0	5	183	3
38	302	4	43	624	15
4	123	2	5	212	0
18	151	6	3	19	0
61	519	19	7	217	2
45	173	13	10	267	0
7	131	0	59	759	21
10	290	1	6	128	2
2	270	2	8	181	2
0	4	0	5	148	2
5	29	1	2	5	2
10	258	1	5	195	0
4	101	0	6	252	0
3	31	0	10	190	8
10	70	3	8	342	3
2	22	1	13	235	13
2	90	1	12	107	10

1	6	1	27	317	12
1	10	0	9	134	5
32	327	10	8	103	6
18	329	7	11	144	6
22	93	8	18	153	9
4	23	2	3	18	0
45	489	8	1	4	0
20	409	9	1	16	1
11	41	7	16	138	9
1	70	0	4	104	1
3	37	1	7	200	3
10	26	0	4	123	2
10	116	5	7	50	3
29	434	9	12	180	7
6	38	3	12	95	4
1	7	0	25	215	7
5	160	2	9	124	6
65	737	25	14	254	10
16	61	5	16	266	7
30	214	6	9	192	6
2	16	1	15	238	7
29	342	9	9	210	5
13	182	1	13	259	8
36	468	12	17	312	9
17	198	4	49	842	21
3	4	2	7	43	1
27	356	14	21	316	13
21	235	6	24	243	11
17	136	7	22	377	9
21	154	8	30	420	16
22	384	5	22	339	8
2	48	1	14	264	5
0	20	0	7	174	4
2	12	2	3	6	0
2	14	0	6	36	6
2	53	0	16	316	11
1	6	0	0	1	0
7	117	1			

C. The record of leaf area and triangle area, length and width.

Δ length	Δ width	leaf area	Δ area	tri./leaf percent	Δ length	Δ width	leaf area	Δ area	tri./leaf percent
25	55	5830	688	12	22	40	3650	440	12
22	40	4420	440	10	20	35	4870	350	7

17	30	3700	255	7	25	50	5010	620	12
20	35	4530	350	8	25	45	6600	563	9
22	35	3810	385	10	23	40	4760	460	10
25	50	5660	500	9	25	40	6200	500	8
24	37	3560	444	13	24	38	4530	456	10
18	35	3140	315	10	19	35	4070	333	8
23	32	3140	368	12	23	41	4700	472	10
25	35	3510	438	13	25	40	3940	500	13
16	30	3090	240	8	21	35	4510	368	8
20	31	3150	310	10	26	45	6670	585	9
21	30	3500	315	9	25	40	5410	500	9
25	54	5800	675	12	26	40	4990	520	10
25	46	6180	575	9	27	55	7170	743	10
13	30	2810	195	7	25	45	5000	563	11
28	45	4410	630	14	22	40	4400	440	10
30	58	8200	870	11	26	35	4180	455	11
22	32	2960	352	12	22	40	5320	440	8
17	24	2200	204	9	27	45	6870	608	9
15	22	1810	165	9	27	50	6670	675	10
25	40	3690	500	14	32	50	6810	800	12
21	26	3540	273	8	25	42	5820	525	9
20	35	3110	350	11	24	40	4310	480	11
32	50	6640	800	12	29	38	6850	551	8
21	40	3380	420	12	22	50	6130	550	9
30	55	7180	825	12	27	38	4190	513	12
26	31	4080	403	10	23	40	4270	460	11
25	42	4380	525	12	21	40	5260	420	8
19	25	2570	238	9	30	50	6400	750	12
22	35	4080	385	9	27	46	5480	621	11
25	45	5540	562	10	22	45	4360	495	11
25	40	4320	500	12	22	40	4220	440	10
25	50	6480	625	10	19	35	3700	333	9
24	50	6600	600	9					

Appendix 6.1. Mean wet weight of cones per vine from seven treatments.

TREATMENTS						
1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
302.02	410.25	215.67	244.67	223.40	208.00	278.18
270.67	289.30	172.70	218.37	253.33	264.15	182.65
380.63	340.50	194.88	223.43	248.25	271.26	203.75
240.93	349.30	193.45	249.38	244.75	251.70	250.00
395.63	338.20	244.12	318.53	376.60	181.63	234.67
161.97	265.28	201.74	201.55	326.33	210.64	246.50
232.15	269.40	176.87	223.70	404.50	173.83	213.00
231.40	239.95	217.37	234.93	451.60	94.43	202.27
197.35	214.38	201.26	312.65	226.30	205.50	335.27
365.57	308.97	84.23	211.90			297.20
311.53	254.53	125.2	246.80			297.33
189.90	196.63	126.13	382.75			
208.78	313.57	213.70				
282.17	255.85	199.20				
408.63	269.80	218.85				
	238.00	259.75				
	187.85	182.05				
		276.62				
		207.85				
		157.58				
		213.37				

Appendix 6. 2. One-way ANOV for yields from seven treatments (mean wet weight of cones/vine) (Zar 1984, pp. 162-67).

	TREATMENTS						
	1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
Count	15	17	21	12	9	9	11
Σ	4179.33	4741.76	4082.59	3068.66	2755.06	1861.14	2740.82
Mean	278.62	278.93	194.41	255.72	306.12	206.79	249.17
Std. Dev.	79.75	58.97	44.72	54.20	86.12	54.57	48.06

Table of ANOV

H_o: $\mu_1 = \mu_2 = ... = \mu_7$, all the mean weight of wet cone per vine are equal;

H_a: $\mu_1 \neq \mu_2 \neq ... \neq \mu_7$, the mean weight of wet cone /vine are not all equal.

Source of variation	SS	DF	MS	
Total		460131.07		93
Group	136902.49	6	22817.08	
Error	323228.58	87	3715.27	

F = Group MS /Error MS = 6.1414

$F_{0.05\,(1),\,6,\,87} = 2.20$ Reject H_o p <<<0.0005

Therefore, the mean wet cone weight per vine are not all equal among the seven different treatments.

Appendix 6.3. Newman-Keuls multiple range test for mean wet weight of cones/vine from treatments (Zar 1984, p.186-191).

Treatment	U-C	2-S	3-S	2-O	C-S	P-P	3-O
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	194.41	206.79	249.17	255.72	278.62	278.93	306.12
Sample Size (n_i)	21	9	11	12	15	17	9

Comparison B vs A	Difference $x_B - x_A$	SE *	q **	p ***	$q_{0.05, 87, p}$	Conclusion
1 vs 7	-111.71	17.17	6.51	7	4.241	Reject H_o $\mu_1 = \mu_7$
1 vs 6	-84.52	14.06	6.01	6	4.096	Reject Ho $\mu_1 = \mu_6$
1 vs 5	-84.21	14.57	5.78	5	3.917	Reject H_o $\mu_1 = \mu_5$
1 vs 4	-61.31	15.60	3.93	4	3.685	Reject H_o $\mu_1 = \mu_4$
1 vs 3	-54.76	16.04	3.41	3	3.356	Reject H_o $\mu_1 = \mu_3$
1 vs 2	-12.38	17.17	0.72	2	2.800	Accept H_o $\mu_1 = \mu_2$

*: $SE = (s^2/2^* (1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = The range of means

Therefore, $\mu_1 = \mu_2$; $\mu_1 \neq \mu_3$; $\mu_1 \neq \mu_4$; $\mu_1 \neq \mu_5$; $\mu_1 \neq \mu_6$; $\mu_1 \neq \mu_7$.

Conclusion: The mean wet weight of cones per vine from untreated controls is equal to that from sulphur-2-spray, but not to the rest of the means.

Appendix 6. 4. Mean wet weight per cone from treatments.

Treatments*						
1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
.46920	.5088	.4539	.5069	.53920	.49590	.6229
.41950	.4753	.3622	.4667	.57632	.57138	.5179
.40970	.5007	.3589	.4324	.54500	.53550	.3792
.46200	.5578	.6045	.58768	.64390	.51940	.4408
.49820	.5872	.5088	.63250	.72970	.52620	.4258
.47430	.4949	.4993	.65450	.55770	.58654	.55970
.28225	.5325	.39164	.46230	.57730	.38850	.52320
.33050	.5250	.37420	.51880	.60380	.39950	.52380
.32860	.5256	.38170	.43780	.52270	.40800	.4280
.43115	.4895	.3727	.61870			.46640
.41320	.5410	.4140	.53890			.52620
.46760	.5101	.4601	.52980			
.44210	.4758	.5220				
.51060	.4959	.5052				
.47880	.5430	.4895				
	.5156	.5893				
	.5413	.4825				
		.5232				
		.4489				
		.4845				
		.4993				

Appendix 6. 5. One-way ANOV for mean wet weight per cone from seven treatments (Zar 1984, pp. 162-67).

	TREATMENTS						
	1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
Count	15	17	21	12	9	9	11
Mean	0.4278	0.5188	0.4632	0.5322	0.5884	0.4923	0.4922
Std. Dev.	0.0667	0.0299	0.0716	0.0766	0.0643	0.0753	0.0707

Table of ANOV

H_o: $\mu_1 = \mu_2 = ... = \mu_7$, all the mean weights of each wet cone are equal;

H_a: $\mu_1 \neq \mu_2 \neq ... \neq \mu_7$, the mean weights of each wet cone are not all equal.

Source of variation	SS	DF	MS
Total		0.566	93
Group	0.194	6	0.32
Error	0.372	87	0.004

F = Group MS /Error MS = 7.553

$F_{0.05\,(1),\,6,\,87} = 2.20$ Reject H_o $p < 0.0005$

Therefore, the mean weights of each wet cone are not all equal among the seven different treatments.

Appendix 6.6. Dunnett's test for comparing one mean to each other group (mean wet weight/cone) (Zar 1984, pp. 194-195).

Treatment	C-S	U-C	3-S	2-S	P-P	2-O	3-O
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	0.4278	0.4632	0.4922	0.4923	0.5188	0.5322	0.5884
Sample Size (n_i)	15	21	11	9	17	12	9

Group one is the 'control' group. To test H_o: $\mu_1 \geq \mu_a$ against H_a: $\mu_1 < \mu_a$

Comparison B vs A	Difference $x_B - x_A$	SE *	|q| **	p ***	$q_{0.05(1)\,87,p}$	Conclusion
1 vs 7	0.1606	0.0267	6.02	7	2.32	Reject H_o: $\mu_1 \geq \mu_7$
1 vs 6	0.1044	0.0245	4.26	6	2.26	Reject H_o: $\mu_1 \geq \mu_6$
1 vs 5	0.091	0.0224	4.06	5	2.18	Reject H_o: $\mu_1 \geq \mu_5$
1 vs 4	0.0645	0.0267	2.42	4	2.08	Reject H_o: $\mu_1 \geq \mu_4$
1 vs 3	0.0644	0.0251	2.57	3	1.93	Reject H_o: $\mu_1 \geq \mu_3$
1 vs 2	0.0354	0.0214	1.65	2	1.66	Accept H_o: $\mu_1 \geq \mu_2$

Therefore, the mean wet weight per cone from commercially sprayed crop is not less than that of untreated control, but less than those of all the other treatments.

Appendix 6.6. Dunnett's test for comparing one mean to each other group (mean wet weight/cone) *(continued)*

Group two is the 'control' group. To test H_0: $\mu_2 \geq \mu_a$ against H_a: $\mu_2 < \mu_a$

2 vs 7	0.1252	0.0252	4.97	6	2.26	Reject H_0: $\mu_2 \geq \mu_7$
2 vs 6	0.0690	0.0229	3.01	5	2.18	Reject H_0: $\mu_2 \geq \mu_6$
2 vs 5	0.0556	0.0206	2.70	4	2.08	Reject H_0: $\mu_2 \geq \mu_5$
2 vs 4	0.0291	0.0252	1.16	3	1.93	Accept H_0: $\mu_2 \geq \mu_4$
2 vs 3	0.0290	0.0235	1.23	2	1.66	Accept H_0: $\mu_2 \geq \mu_3$
2 vs 1	-0.0354	0.0214	1.65	2	1.66	Accept H_0: $\mu_2 \geq \mu_1$

Therefore, the mean wet weight per cone of untreated crop is not less than those of sulphur-2-spray, sulphur-3-spray and commercially sprayed crops, but less than those of the other treatments.

*: $SE = (s^{2*} (1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = The range of means.

s^2 = Error MS = 0.004

Appendix 6. 7. Record of mean dry weight per cone from treatments.

Treatments						
1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
.12556	.15116	.14658	.15912	.14984	.13732	.19564
.10876	.12972	.11192	.14152	.16584	.15546	.16958
.10322	.13182	.11938	.13614	.15186	.14122	.11642
.12924	.15314	.17618	.18168	.18330	.15056	.14918
.12460	.15560	.14956	.19546	.20084	.14196	.14608
.12722	.13364	.1588	.21058	.16486	.15862	.15490
.09494	.14716	.11874	.12732	.14980	.10212	.15404
.09624	.14010	.11332	.14030	.16466	.10378	.15356
.10028	.1491	.12380	.11500	.13834	.09846	.10890
.12710	.12994	.09244	.15554			.12626
.12216	.14038	.10162	.14380			.14458
.13826	.1386	.10874	.13174			
.12482	.12386	.15506				
.14738	.1310	.14502				
.13860	.1419	.14902				
	.13284	.14674				
	.13758	.11912				
		.12332				
		.11378				
		.12018				
		.12686				

Appendix 6. 8. One-way ANOV for average dry weight per cone from seven treatments (Zar 1984, pp. 162-67).

	TREATMENTS*						
	1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
Count	15	17	21	12	9	9	11
Mean	0.1206	0.1393	0.1295	0.1532	0.1633	0.1322	0.1472
Std. Dev.	0.0162	0.0093	0.0214	0.0289	0.0192	0.0241	0.0242

Table of ANOV

H_o: $\mu_1 = \mu_2 = ... = \mu_7$, all the mean weights of each dry cone are equal;

H_a: $\mu_1 \neq \mu_2 \neq ... \neq \mu_7$, the mean weights of each dry cone are not all equal.

Source of variation	SS	DF	MS
Total	0.053	93	
Group	0.016	6	0.003
Error	0.037	87	0.00042

F = Group MS /Error MS = 6.22

$F_{0.05\,(1),\,6,\,87} = 2.20$ Reject H_o $p << 0.0005$

Therefore, the dry mean weights of each cone are not all equal among the seven different treatments.

Appendix 6.9. Dunnett's test for comparing one mean to each other group (mean dry weight/cone) (Zar 1984, p.194-5).

Treatment	C-S	U-C	2-S	P-P	3-S	2-O	3-O
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	0.1206	0.1295	0.1322	0.1393	0.1472	0.1532	0.1633
Sample Size (n_i)	15	21	9	17	11	12	9

Group one is the 'control' group. To test H_o: $\mu_1 \geq \mu_a$ against H_a: $\mu_1 < \mu_a$

Comparison B vs A	Difference $x_B - x_A$	SE *	|q| **	p ***	$q_{0.05(1)\,87,\,p}$	Conclusion
1 vs 7	0.0427	0.0084	5.08	7	2.32	Reject H_o: $\mu_1 \geq \mu_7$
1 vs 6	0.0326	0.0078	4.18	6	2.26	Reject H_o: $\mu_1 \geq \mu_6$
1 vs 5	0.0266	0.0079	3.37	5	2.18	Reject H_o: $\mu_1 \geq \mu_5$
1 vs 4	0.0187	0.0071	2.63	4	2.08	Reject H_o: $\mu_1 \geq \mu_4$
1 vs 3	0.0116	0.0084	1.38	3	1.93	Accept H_o: $\mu_1 \geq \mu_3$
1 vs 2	0.0089	0.0068	1.31	2	1.66	Accept H_o: $\mu_1 \geq \mu_2$

Therefore, the mean dry weight per cone from commercially sprayed crop is not less than those of sulphur-2-sprayed and untreated controlment crops, but less than those of all the other treatments.

Appendix 6.9. Dunnett's test for comparing one mean to each other group (mean dry weight/cone) *(continued)*

Group two is the 'control' group. To test H_0: $\mu_2 \geq \mu_a$ against H_a: $\mu_2 < \mu_a$

2 vs 7	0.0338	0.0080	4.23	6	2.26	Reject H_0: $\mu_2 \geq \mu_7$
2 vs 6	0.0237	0.0072	3.29	5	2.18	Reject H_0: $\mu_2 \geq \mu_6$
2 vs 5	0.0177	0.0074	2.39	4	2.08	Reject H_0: $\mu_2 \geq \mu_5$
2 vs 4	0.0098	0.0065	1.51	3	1.93	Accept H_0: $\mu_2 \geq \mu_4$
2 vs 3	0.0027	0.0080	0.34	2	1.66	Accept H_0: $\mu_2 \geq \mu_3$
2 vs 1	-0.0089	0.0068	1.31	2	1.66	Accept H_0: $\mu_2 \geq \mu_1$

Therefore, the mean dry weight per cone of untreated crop is not less than those of *P. persimilis* released, sulphur-2-spray and commercially sprayed crops, but less than those of the other treatments.

*: $SE = (s^{2*}(1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = The range of means.

s^2 = Error MS = 0.0004

Appendix 6. 11. Numbers of cones /vine from various treatments.

Treatments						
1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
643.6914	806.309	475.142	482.6723	414.318	419.439	446.580
645.2127	608.668	476.808	467.8950	439.556	462.302	352.674
929.0537	680.048	542.979	516.7283	455.505	506.555	537.315
521.5007	626.210	320.017	424.3380	380.106	484.598	567.151
794.1257	575.954	479.795	503.6100	516.103	345.179	551.119
341.4857	536.018	404.046	307.9450	720.100	359.123	440.4150
822.4980	505.916	451.606	483.8850	700.676	447.447	407.1100
700.1513	457.048	580.885	452.8238	747.930	236.379	386.1523
600.5782	407.867	527.273	714.1390	432.944	503.677	783.6997
847.8873	631.240	226.008	342.4922			637.2213
753.9328	470.487	302.415	457.9700			565.0577
406.1162	385.480	274.125	722.4425			
472.2347	659.030	409.387				
552.6180	515.931	394.299				
853.4358	496.869	447.089				
	461.598	440.777				
	347.035	377.306				
		528.708				
		463.021				
		325.232				
		427.332				

Appendix 6. 12. One-way ANOV for mean numbers of cone per vine from seven treatments (Zar 1984, pp. 162-67).

	TREATMENTS						
	1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
Count	15	17	21	12	9	9	11
Mean	659	540	423	490	534	418	516
Std. Dev.	176.44	118.98	92.92	123.35	146.54	89.59	126.09

Table of ANOV

H_o: $\mu_1 = \mu_2 = ... = \mu_7$, all the mean number of cone per vine are all equal;

H_a: $\mu_1 \neq \mu_2 \neq ... \neq \mu_7$, the mean number of cone /vine are not all equal.

Source of variation	SS	DF	MS
Total	19916607.70	93	
Group	594241.47	6	99040.245
Error	1397366.23	87	16061.68

F = Group MS /Error MS = 6.166

$F_{0.05\,(1),\,6,\,87} = 2.20$ Reject H_o $p <<< 0.0005$

Therefore, the mean numbers of cone per vine are not all equal among the seven different treatments.

Appendix 6.13. Dunnett's test for comparing one mean to each other group (numbers of cones per vine) (Zar 1984, 194-5).

Treatment	2-S	U-C	2-O	3-S	3-O	P-P	C-S
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	418	423	490	516	534	540	659
Sample Size (n_i)	9	21	12	11	9	17	15

Group seven is the 'control' group. To test H_0: $\mu_7 \leq \mu_a$ against H_a: $\mu_7 > \mu_a$

Comparison B vs A	Difference $x_B - x_A$	SE *	|q| **	p ***	$q_{0.05(1)\,87,\,p}$	Conclusion
7 vs 1	241	53.44	4.51	7	2.32	Reject H_0: $\mu_7 \leq \mu_1$
7 vs 2	236	42.84	5.51	6	2.26	Reject H_0: $\mu_7 \leq \mu_2$
7 vs 3	169	49.08	3.44	5	2.18	Reject H_0: $\mu_7 \leq \mu_3$
7 vs 4	143	50.31	2.84	4	2.08	Reject H_0: $\mu_7 \leq \mu_4$
7 vs 5	125	53.44	2.34	3	1.93	Reject H_0: $\mu_7 \leq \mu_5$
7 vs 6	119	44.90	2.65	2	1.66	Reject H_0: $\mu_7 \leq \mu_6$

Therefore, the mean number of cones per vine from commercially sprayed crop is greater than those of all the other treatments.

Appendix 6.13. Dunnett's test for comparing one mean to each other group (numbers of cones per vine) *(continued)*

Group one is the 'control' group. To test H_0: $\mu_2 \geq \mu_a$ against H_a: $\mu_2 < \mu_a$

2 vs 7	-236	42.84	5.51	6	2.26	Reject H_0: $\mu_2 \geq \mu_7$
2 vs 6	-107	41.35	2.59	5	2.18	Reject H_0: $\mu_2 \geq \mu_6$
2 vs 5	-111	50.49	2.20	4	2.08	Reject H_0: $\mu_2 \geq \mu_5$
2 vs 4	--93	47.17	1.97	3	1.93	Reject H_0: $\mu_2 \geq \mu_4$
2 vs 3	-67	45.86	1.46	2	1.66	Accept H_0: $\mu_2 \geq \mu_3$
2 vs 1	5	50.49	0.10	2	1.66	Accept H_0: $\mu_2 \geq \mu_1$

Therefore, the mean number of cones per vine of untreated crop is not less than those of sulphur-2-spray and oil-2-spray crops, but less than those of the other treatments.

*: $SE = (s^{2*} (1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = The range of means.

s^2 = Error MS = 16062

Appendix 6.14. Dry cone weights / vine from the seven different treatments.

Treatments						
1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
80.82	121.88	69.65	76.80	62.08	57.60	87.37
70.17	78.96	53.36	66.22	72.90	71.87	59.81
95.90	89.64	64.82	70.35	69.17	71.54	62.55
67.40	95.90	56.38	77.09	69.67	72.96	84.61
98.95	89.62	71.76	98.44	103.65	49.00	80.51
43.44	71.63	64.16	64.85	118.72	56.96	68.22
78.09	74.45	53.62	61.61	104.96	45.69	62.71
67.38	64.03	65.83	63.53	123.15	24.53	59.30
60.23	60.81	65.28	82.13	59.89	49.59	85.35
107.77	82.02	20.89	53.27			80.46
92.10	66.05	30.73	65.86			81.70
56.15	53.43	29.81	95.18			
58.94	81.63	63.48				
81.45	67.59	57.18				
118.29	70.51	66.63				
	61.32	64.68				
	47.75	44.95				
		65.20				
		52.68				
		39.09				
		54.21				

Appendix 6. 15. One-way ANOV for dry yields from seven treatment (Zar 1984, pp. 162-67).

	TREATMENTS*						
	1 (C-S)	2 (P-P)	3 (U-C)	4 (2-O)	5 (3-O)	6 (2-S)	7 (3-S)
Count	15	17	21	12	9	9	11
Σ	1177.08	1277.22	1154.39	875.33	784.19	499.74	812.59
Mean	78.47	75.13	54.97	72.94	87.13	55.53	73.87
Std. Dev.	20.91	17.77	14.25	13.59	25.21	15.69	11.28

Table of ANOV

H_o: $\mu_1 = \mu_2 = ... = \mu_7$, all the mean weight of dry cone per vine are equal;

H_a: $\mu_1 \neq \mu_2 \neq ... \neq \mu_7$, the mean weight of dry cone /vine are not all equal.

Source of variation	SS	DF	MS
Total	36662.0	93	
Group	11063.27	6	1843.88
Error	25598.73	87	294.24

F = Group MS /Error MS = 6.267

$F_{0.05\,(1),\,6,\,87} = 2.20$ Reject H_o $p <<< 0.0005$

Therefore, the dry mean weight of cone per vine are not all equal among the seven different treatments.

Appendix 6.16. Newman-Keuls multiple range test for mean dry weight of cones per vine for different treatments (Zar 1984, pp.186-191).

Treatment	U-C	2-S	2-O	3-S	P-P	C-S	3-O
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	54.97	55.53	72.94	73.87	75.13	78.47	87.13
Sample Size (n_i)	21	9	12	11	17	15	9

Comparison B vs A	Difference $x_B - x_A$	SE *	q **	p ***	$q_{0.05, 87, p}$	Conclusion
7 vs 1	32.16	4.83	6.66	7	4.241	Reject H_o $\mu_7 = \mu_1$
7 vs 2	31.6	5.72	5.53	6	4.096	Reject Ho $\mu_7 = \mu_2$
7 vs 3	14.19	5.35	2.65	5	3.917	Accept H_o $\mu_7 = \mu_3$
7 vs 4	Do not test					
6 vs 1	23.5	4.10	5.73	6	4.096	Reject H_o $\mu_6 = \mu_1$
6 vs 2	22.94	5.11	4.49	5	3.917	Reject H_o $\mu_6 = \mu_2$
6 vs 3	Do not test					
5 vs 1	20.16	3.96	5.09	5	3.917	Reject H_o $\mu_5 = \mu_1$
5 vs 2	19.6	5.00	3.92	4	3.685	Reject H_o $\mu_5 = \mu_2$

Appendix 6.16. Newman-Keuls multiple range test for mean dry weight of cones per vine for different treatments. *(continued)*

5 vs 3	Do not test					
4 vs 1	18.9	4.52	4.19	4	3.685	Reject H_o $\mu_4 = \mu_1$
4 vs 2	18.34	5.45	3.36	3	3.356	Reject H_o $\mu_4 = \mu_2$
4 vs 3	Do not test					
3 vs 1	17.97	4.39	4.09	3	3.356	Reject H_o $\mu_3 = \mu_1$
3 vs 2	17.41	5.35	3.26	2	2.800	Reject H_o $\mu_3 = \mu_2$

*: $SE = (s^2/2^* (1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = the range of means.

s^2 = Error MS = 294.24

Therefore, $\mu_1 = \mu_2 \neq \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$

Conclusion: The mean dry weight of cone per vine from untreated control and sulphur-2-spray are equal but neither is equal to the rest of means, which are all equal to each other.

Appendix 6.17. Dunnett's test for comparing one mean to each other group mean dry weight of cones per vine for different treatments (Zar 1984, pp.194-195).

Treatment	U-C	2-S	2-O	3-S	P-P	C-S	3-O
Ranks(i)	1	2	3	4	5	6	7
Ranked Mean (x_i)	54.97	55.53	72.94	73.87	75.13	78.47	87.13
Sample Size (n_i)	21	9	12	11	17	15	9

Group 6 is the"control" group. To test H_o: $\mu_6 \leq \mu_a$ against H_a: $\mu_6 > \mu_a$

Comparison B vs A	Difference $x_B - x_A$	SE *	|q| **	p ***	$q_{0.05(1)\,87,p}$	Conclusion
6 vs 7	8.66	7.233	1.197	2	1.66	Accept H_o: $\mu_6 \leq \mu_7$
6 vs 5	3.34	6.076	0.550	2	1.66	Accept H_o: $\mu_6 \leq \mu_5$
6 vs 4	4.60	6.809	0.676	3	1.93	Accept H_o: $\mu_6 \leq \mu_4$
6 vs 3	5.53	6.644	0.832	4	2.08	Accept H_o: $\mu_6 \leq \mu_3$
6 vs 2	22.94	7.233	3.172	5	2.18	Reject H_o: $\mu_6 \leq \mu_2$
6 vs 1	23.50	5.799	4.053	6	2.26	Reject H_o: $\mu_6 \leq \mu_1$

Therefore, the dry mean cone weight per vine of commercially sprayed crop is greater than those of untreated control and sulphur-2-spray crops, but not greater than those of the other treatments.

Appendix 6.17. Dunnett's test for comparing one mean to each other group mean dry weight of cones per vine for diffrent treatments. *(continued)*

Group one is the "control" group. To test H_o: $\mu_1 \geq \mu_a$ against H_a: $\mu_1 < \mu_a$

1 vs 7	32.16	6.834	4.706	7	2.32	Reject H_o: $\mu_1 \geq \mu_7$
1 vs 6	23.5	5.799	4.053	6	2.26	Reject H_o: $\mu_1 \geq \mu_6$
1 vs 5	20.16	5.596	3.602	5	2.18	Reject H_o: $\mu_1 \geq \mu_5$
1 vs 4	18.9	6.384	2.960	4	2.08	Reject H_o: $\mu_1 \geq \mu_4$
1 vs 3	17.97	6.207	2.895	3	1.93	Reject H_o: $\mu_1 \geq \mu_3$
1 vs 2	0.56	6.834	0.082	2	1.66	Accept H_o: $\mu_1 \geq \mu_2$

Therefore, the dry mean cone weight per vine of untreated crop is not smaller than that of sulphur-2-spray crop, but smaller than those of the other treatments.

*: $SE = (s^{2*} (1/n_A + 1/n_B))^{1/2}$; **: $q = (x_B - x_A)/SE$; ***: p = the range of means.

s^2 = Error MS = 294.24

Appendix 6.18. The presentation of parameters for hop production in 1988-89 (two groups: commercially sprayed crops and non-sprayed crops).

Treatments	Parameters* 1 (g)	2 (g)	3 (g)	4 (g)	5
Comm. Sprd.	495.533	141.664	0.5086	0.1454	974
Comm. Sprd.	354.85	100.908	0.5412	0.1539	656
Comm. Sprd.	671.15	175.345	0.5795	0.1514	1158
Comm. Sprd.	608.433	201.348	0.4297	0.1422	1416
Comm. Sprd.	398.829	111.683	0.4246	0.1189	939
Comm. Sprd.	490.35	143.792	0.4706	0.138	1042
Comm. Sprd.	668.8	192.243	0.454	0.1305	1473
Comm. Sprd.	397.333	117.666	0.3782	0.112	1051
Comm. Sprd.	509.433	146.404	0.5129	0.1474	993
Comm. Sprd.	393.48	106.378	0.5245	0.1418	750
Comm. Sprd.	494.65	138.024	0.4469	0.1247	1107
Comm. Sprd.	430.04	128.039	0.5216	0.1553	825
Comm. Sprd.	553.4	153.605	0.3945	0.1095	1403
Comm. Sprd.	578.64	161.055	0.5091	0.1417	1137
Comm. Sprd.	548.4	149.361	0.492	0.134	1115
Comm. Sprd.	320.067	92.9	0.5037	0.1462	635
Comm. Sprd.	467.6	128.663	0.5426	0.1493	862
Comm. Sprd.	335.45	99.317	0.5475	0.1621	613
Non-spray	558.4	146.802	0.504	0.1325	1108
Non-spray	434.1	124.805	0.4233	0.1217	1026
Non-spray	508.9	129.571	0.4827	0.1229	1054
Non-spray	459.22	125.469	0.422	0.1153	1088
Non-spray	558.025	157.315	0.4473	0.1261	1248
Non-spray	411.067	100.988	0.4506	0.1107	912
Non-spray	419.7	106.917	0.4636	0.1181	905
Non-spray	381.8	112.274	0.455	0.1338	839
Non-spray	479.7	127.981	0.5225	0.1394	918
Non-spray	434.8	120.57	0.5092	0.1412	854
Non-spray	403.75	110.161	0.545	0.1487	741
Non-spray	347.029	93.493	0.4302	0.1159	807
Non-spray	408.143	116.033	0.4126	0.1173	989
Non-spray	676.067	194.264	0.403	0.1158	1678
Non-spray	455.76	117.403	0.5757	0.1483	792
Non-spray	348.111	91.33	0.5988	0.1571	581
Non-spray	386.7	108.586	0.5032	0.1413	769
Non-spray	353.7	106.892	0.5109	0.1544	692
Non-spray	405	122.796	0.4126	0.1251	982
Non-spray	460.08	131.986	0.4793	0.1375	960

Non-spray	401.689	111.61	0.5287	0.1469	760
Non-spray	579.2	152.399	0.545	0.1434	1063
Non-spray	393.886	111.867	0.5028	0.1428	783
Non-spray	668.067	186.332	0.5188	0.1447	1288
Non-spray	436.114	119.786	0.5017	0.1378	869
Non-spray	540	153.511	0.5375	0.1528	1005
Non-spray	439.08	120.608	0.474	0.1302	926
Non-spray	431.9	116.822	0.5309	0.1436	814
Non-spray	466.16	133.231	0.4678	0.1337	997
Non-spray	389.025	91.877	0.5767	0.1362	675
Non-spray	441.5	122.798	0.494	0.1374	893
Non-spray	588.52	166.72	0.4649	0.1317	1266
Non-spray	454.367	132.942	0.5113	0.1496	889
Non-spray	348.367	95.111	0.5908	0.1613	590
Non-spray	469.3	126.276	0.5374	0.1446	873
Non-spray	392.1	105.484	0.5375	0.1446	730
Non-spray	533.067	152.256	0.4709	0.1345	1132
Non-spray	467.225	123.03	0.4523	0.1191	1033
Non-spray	457.4	131.544	0.4416	0.127	1036
Non-spray	416.7	115.618	0.5262	0.146	792
Non-spray	483.6	141.243	0.4588	0.134	1054
Non-spray	404.767	111.428	0.4755	0.1309	851
Non-spray	703.75	194.211	0.466	0.1286	1510
Non-spray	473.95	134.642	0.4995	0.1419	949
Non-spray	345.533	97.398	0.5027	0.1417	687
Non-spray	333.2	93.213	0.5269	0.1474	632
Non-spray	491.4	128.397	0.5936	0.1551	828
Non-spray	418	110.945	0.4864	0.1291	859
Non-spray	375.12	102.382	0.4906	0.1339	765
Non-spray	497.05	141.487	0.4307	0.1226	1154
Non-spray	433.68	125.026	0.4714	0.1359	920
Non-spray	329.167	92.101	0.4807	0.1345	685
Non-spray	383.1	109.668	0.4419	0.1265	867
Non-spray	391.48	111.036	0.4252	0.1206	921
Non-spray	369.8	108.568	0.4193	0.1231	882
Non-spray	424.48	120.505	0.4854	0.1378	875

*:1 = mean wet cone weight per vine for each string;
2 = mean dry cone weight per vine for each string;
3 = mean wet weight per cone for each string;
4 = mean dry weight per cone for each string;
5 = number of cones per vine for each string.

Appendix 6.19. One-way ANOV for mean wet weight of cones per vine for sprayed and unsprayed crops (1988-89). (Zar 1984, pp. 162-67).

	TREATMENTS	
	Comm. Sprd.	Untreated control
Count	18	56
Mean	484.247	447.532
Std. Dev.	107.176	83.53

Table of ANOV

H_o: $\mu_1 = \mu_2$, the mean wet cone weight per vine are equal;

H_a: $\mu_1 \neq \mu_2$, the mean wet cone weight per vine are not equal.

Source of variation	SS	DF	MS
Total	597384.401	73	
Group	18361.31	1	18361.31
Error	579023.09	72	8041.987

F = Group MS /Error MS = 2.283

$F_{0.05\,(1),\,1,\,72} = 3.98$ Accept H_o $p = 0.1352$

Therefore, the mean wet cone weight per vine are equal for the two treatments.

Appendix 6.20. One-way ANOV for mean wet weight per cone from two treatments (1988-89). (Zar 1984, pp. 162-67).

	TREATMENTS	
	Comm. Sprd.	Untreated crop
Count	18	56
Mean	0.488	0.490
Std. Dev.	0.056	0.049

Table of ANOV

H_o: $\mu_1 = \mu_2$, both the mean wet weight per cone are equal;

H_a: $\mu_1 \neq \mu_2$, the mean wet weight per cone are not equal.

Source of variation	SS	DF	MS
Total	0.184	73	
Group	0.00004	1	0.00004
Error	0.184	72	0.003

F = Group MS /Error MS = 0.016

$F_{0.05\,(1),\,1,\,72} = 3.98$ Accept H_o $p = 0.9007$

Therefore, the mean weights of each wet cone are equal for the two treatments.

Appendix 6.21. One-way ANOV for mean weights per dry cone from two treatments (1988-89). (Zar 1984, pp. 162-67).

	TREATMENTS*	
	Comm. Sprd.	Untreated crop
Count	18	56
Mean	0.139	0.135
Std. Dev.	0.015	0.012

Table of ANOV

H_o: $\mu_1 = \mu_2$, the mean weights of each dry cone are equal;

H_a: $\mu_1 \neq \mu_2$, the mean weights of each dry cone are not equal.

Source of variation	SS	DF	MS
Total	0.012	73	
Group	0.000204	1	0.000204
Error	0.012	72	0.000161

F = Group MS /Error MS = 1.266

$F_{0.05\,(1),\,1,\,72} = 3.98$ Accept H_o $p = 0.2643$

Therefore, the mean dry weight per cone are equal for the two treatments.

Appendix 6.22. One-way ANOV for numbers of cone per vine from two treatments (1988-89). (Zar 1984, pp. 162-67).

	TREATMENTS	
	Comm. Sprd.	Untreated crop
Count	18	56
Mean	1008	925
Std. Dev.	259.94	206.74

Table of ANOV

H_o: $\mu_1 = \mu_2$, the mean number of cone per vine are all equal;

H_a: $\mu_1 \neq \mu_2$, the mean number of cone /vine are not all equal.

Source of variation	SS	DF	MS
Total	3594014.219	73	
Group	94635.135	1	94635.135
Error	3499379.084	72	48602.487

F = Group MS /Error MS = 1.947

$F_{0.05\,(1),\,1,\,72} = 3.98$ Accept H_o $p = 0.1672$

Therefore, the mean numbers of cone per vine are all equal for the two treatments.

Appendix 6.23. One-way ANOV for mean dry cone weight per vine from two treatments (1988-89) (Zar 1984, pp. 162-67).

	TREATMENTS	
	Comm. Sprd.	Untreated crop
Count	18	56
Mean	138.244	123.888
Std. Dev.	31.22	23.86

Table of ANOV

H_o: $\mu_1 = \mu_2$, the mean weights of dry cone per vine are all equal;

H_a: $\mu_1 \neq \mu_2$, the mean weights of dry cone per vine are not all equal.

Source of variation	SS	DF	MS
Total	50691.075	73	
Group	2807.549	1	2807.549
Error	47883.525	72	665.049

F = Group MS /Error MS = 4.222

$F_{0.05\,(1),\,1,\,72} = 3.98$ Reject H_o $p = 0.0435$

Therefore, the mean dry cone weight per vine are not equal for the two treatments.
